*Review Draft – March 3, 2003*

# South Prairie Creek Bacteria and Temperature Total Maximum Daily Load Study

March 2003

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**Memorandum**

To: Files

From: Mindy Roberts

Date: April 23, 2003

Subject: Errata for draft South Prairie Creek Bacteria and Temperature Total Maximum Daily Load Study

The following errors will be corrected in the final technical study report:

- Page 9, Figure 3 — Stations SPCID and SPCOF did not meet water quality standards.

- Page 17, Table 4 — Stations SPCOF and SPCID did not meet water quality standards. The geometric mean and 90th percentile values are correct.

- Page 20, Wasteload Allocations — Because the unnamed tributary from the town of South Prairie (stations T1 and T1ID) is a part of Pierce County's stormwater conveyance system, the load reductions are considered wasteload allocations (from a point source) rather than load allocations (from nonpoint sources). The load reduction factors do not change, but the Wasteload Allocations section will include a new paragraph including the reduction factors specifically as wasteload allocations.

- Page 27, Water Temperature, Air Temperature, and Relative Humidity — Data were not presented in Appendix A, although this was referenced in the text.

- Page 44, last sentence — 18.°C should be 18.8°C.

- Page 50, equation — Equation should be $T_{wwtp} < 0.452/Q_{wwtp} + 18.1$. Delete footnotes. ($Q_{wwtp}$ in mgd, $T_{wwtp}$ in °C)

- Page 52, equation — Equation should be $T_{wwtp} < 0.104/Q_{wwtp} + 18.1$. Delete footnotes. ($Q_{wwtp}$ in mgd, $T_{wwtp}$ in °C)

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WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

# South Prairie Creek Temperature and Bacteria Total Maximum Daily Loads


*by*
*Mindy Roberts*

Environmental Assessment Program
Olympia, Washington 98504-7710


March 2003

Waterbody Numbers:
10-1085/VC19MO and 10-1087/NX07HW
WA-10-1085


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# Abstract

The South Prairie Creek watershed, located in WRIA 10, covers 90.7 $mi^2$ (235 $km^2$) and includes all or portions of the towns of Wilkeson, Buckley, South Prairie and Burnett. The creek, a Class A water body, is a tributary to the Carbon River, located in the Puyallup River watershed. Segments of South Prairie Creek or its tributaries were placed on the 303(d) list of impaired waters for fecal coliform, temperature, and copper.

Historical fecal coliform bacteria concentrations along lower South Prairie Creek reached a geometric mean of 132 with four of 12 samples exceeding 200/100 ml, resulting in the inclusion to the 1996 and 1998 303(d) lists. The present study identifies and quantifies the sources of fecal coliform bacteria from Spiketon Road in Buckley to the confluence with the Carbon River. The South Prairie Creek load allocations call for fecal coliform bacteria load reductions between the town of South Prairie and station SPCB4 of 41% during the growing season (May through October) and 77% during the non-growing season (November through April). In addition, fecal coliform loads must be reduced by 84% and 52% in Spiketon Creek/Ditch during the growing season and non-growing season. Fecal coliform bacteria loads in the unnamed tributary leaving the town of South Prairie from the northwest must be reduced by 90% and 93% in the growing and non-growing seasons, respectively.

Wilkeson Creek was placed on the 303(d) list for temperature based on monitoring conducted in 1997 by the Muckleshoot Tribe. Upper South Prairie Creek originally was listed for temperature incorrectly by comparison with the Class AA temperature standards; the original data did meet the Class A temperature standard. However, continuous temperature monitoring in 2000 and 2001 indicated that some segments of South Prairie Creek and its tributaries exceed the Class A temperature standard. Thus, a temperature TMDL was conducted. The temperature assessment uses effective shade as a surrogate measure of heat flux to fulfill the requirements of the Clean Water Act. Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. The present study recommends load allocations equivalent to mature riparian vegetation throughout the watershed. The South Prairie and Wilkeson wastewater treatment plants should not increase stream temperatures at the edge of the mixing zone by >0.1°C.

A recent re-evaluation of the copper listing on Wilkeson Creek found that waters are within water quality standards for copper during critical conditions (Golding and Johnson, 2001) and recommended that the listing be removed. Therefore, no TMDL analysis was conducted.

# Acknowledgements

We would like to thank the following people for their contribution to this study:

- Jeannette Barreca, Karol Erickson, Greg Pelletier (Ecology) and Laurie Best-Mann (EPA) for review of the draft report.
- Stephanie Brock, Sarah O'Neal, Dustin Bilhimer, Debby Sargeant, Lynel Rabago, Dana Mock, Trevor Swanson, Jim Garner, Chris Peredney, Jodie Beall, Anita Stohr, Greg Pelletier, Morgan Roose, Tara Galuska, John Summers VII, and the Stream Hydrology Unit (Ecology) for field assistance.
- Aspen Madrone (Ecology) for GIS support and delineation of vegetation.
- Larry Harter (South Prairie Utilities) for identifying discharge location and local information.
- KC Crusaders Paintball, the Britschgi residence, Inglin Dairy, and the Tait residence for allowing access to monitoring locations.
- Russ Ladley and Char Naylor (Puyallup Tribe) for background information on the system and access to results of ongoing data collection programs.
- Jeffrey Light (Plum Creek Timber Company, Inc.) for providing temperature monitoring data within private forest lands.
- John Collins (Pierce County Water Programs) and Margaret Hill (Ecology) for assistance in evaluating potential sources of contamination in Spiketon Creek/Ditch.
- Adriana Franz and Betsy Dickes (Ecology) for coordination with dairies.

# Introduction

Section 303(d) of the federal Clean Water Act mandates that states establish Total Maximum Daily Loads (TMDLs) for surface waters that do not meet standards after application of technology-based pollution controls. The U.S. Environmental Protection Agency (EPA) has promulgated regulations (40 CFR 130) and developed guidance (EPA, 1991) for establishing TMDLs.

Under the Clean Water Act, each state develops standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses, such as cold water biota and drinking water supply, and criteria, usually numeric values, to achieve those uses. When a lake, river or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state to place the water body on a list of "impaired" water bodies, referred to as the 303(d) list after the Clean Water Act section number, and to prepare an analysis called a Total Maximum Daily Load.

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of both water quality problems and sources of the problems. The TMDL determines the loading capacity, which is the amount of a given pollutant that can be discharged to the water body and still meet standards, and the load and wasteload allocated among various sources. If the pollutant comes from a discrete source (referred to as a point source) such as a wastewater treatment plant discharge, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a diffuse source (referred to as a nonpoint source) such as a residential development, that share is called a load allocation.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge regarding the causes of the water quality problem or a water body's loading capacity. The sum of the load and wasteload allocations and the margin of safety must be equal to or less than the loading capacity of the system.

## Scope and Purpose of the South Prairie Creek TMDLs

This report presents TMDL analyses and recommendations for fecal coliform bacteria and temperature in South Prairie Creek and its tributaries. Figure 1 shows the study area. The 1996 and 1998 303(d) lists identify South Prairie Creek or its tributaries as impaired by fecal coliform bacteria, temperature, and copper. The fecal coliform bacteria listing was based on historical ambient monitoring conducted by Ecology. The original temperature listings on South Prairie Creek and its tributaries were based on data collected by the Muckleshoot Tribe. Subsequent monitoring by Ecology conducted under the present study indicates that much of the lower watershed exceeds the temperature standard. Finally, the copper listing for Wilkeson Creek, originally based on estimates rather than field data, was reevaluated in 2001. Golding and Johnson (2001) concluded that the creek remains in compliance with water quality standards during critical conditions and recommended that Wilkeson Creek no longer be listed for copper. Therefore, no copper TMDL was conducted. The fecal coliform bacteria and temperature analyses are presented in following sections of this report. Table 1 summarizes the water bodies addressed in this study.

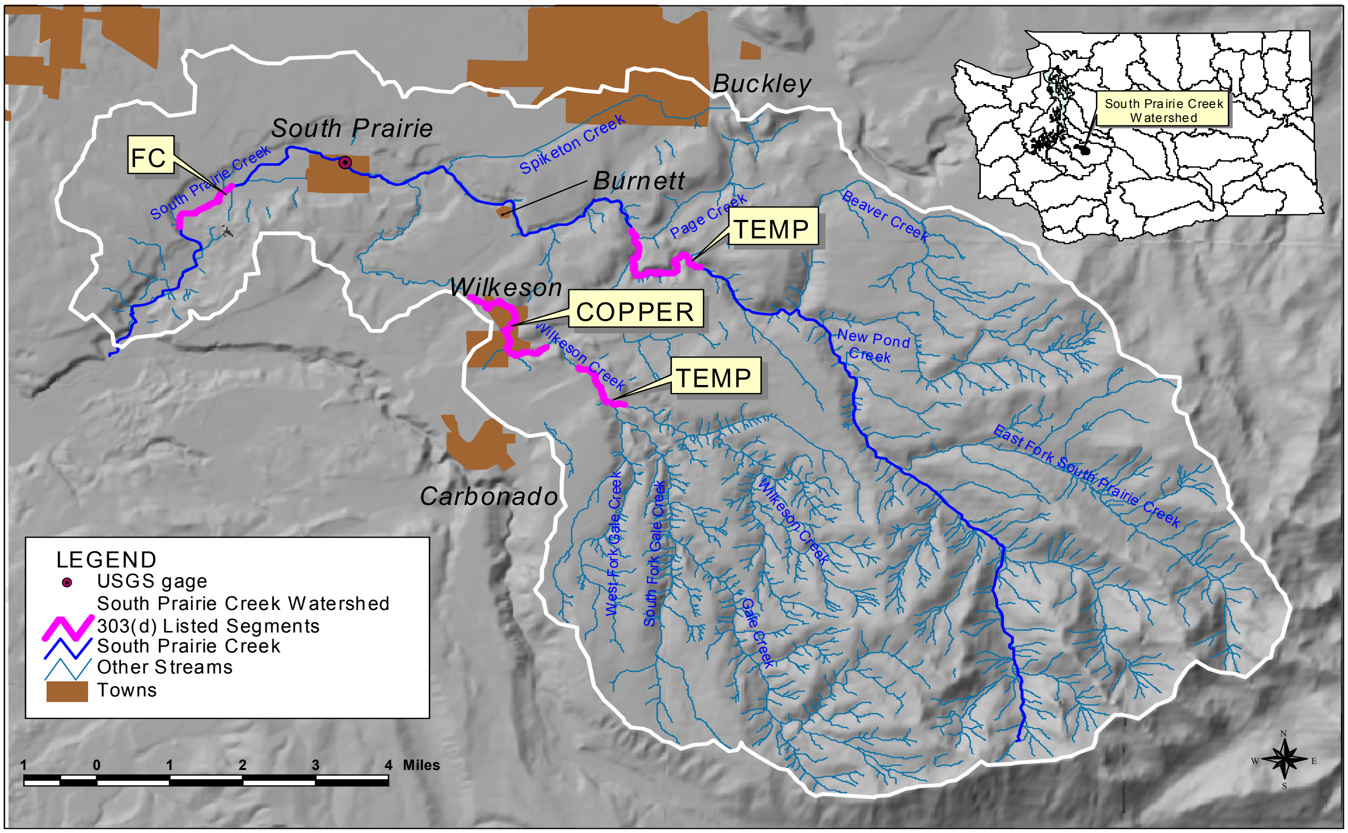



Figure 1. South Prairie Creek watershed with 303(d) listings.

## Pollutants and Surrogate Measures

Fecal coliform bacteria are used by the State of Washington as indicators of pathogens associated with fecal contamination. Fecal pathogens are microorganisms capable of causing disease through ingestion or skin contact. Other indicators, such as *E. coli* and enterococci, have been evaluated as alternative or additional surrogates for pathogens under the triennial review of state water quality standards. However, at the time of publication, fecal coliform bacteria remain the designated indicator.

Table 1. Streams addressed in the fecal coliform bacteria and temperature TMDLs

| Name | Parameter | Old ID | New ID | 1996 303(d) list | 1998 303(d) list | Impaired but not listed |
|---|---|---|---|---|---|---|
| South Prairie Creek | Fecal coliform bacteria | WA-10-1085 | VC19MO | Yes | Yes | |
| Spiketon Creek | Fecal coliform bacteria | (none) | (none) | No | No | Yes |
| Wilkeson Creek | Fecal coliform bacteria | WA-10-1087 | NX07HW | No | No | No |
| Unnamed Tributary | Fecal coliform bacteria | (none) | (none) | No | No | Yes |
| South Prairie Creek | Temperature | WA-10-1085 | VC19MO | Yes* | Yes* | Yes* |
| Spiketon Creek | Temperature | (none) | (none) | No | No | Yes |
| Wilkeson Creek | Temperature | WA-10-1087 | NX07HW | Yes** | Yes** | Yes** |
| Gale Creek | Temperature | WA-10-1087 | NX07HW | Yes | Yes | |

*South Prairie Creek was monitored by the Muckleshoot Tribe and subsequently placed on the 303(3) list in error by comparison with the Class AA water quality standards. However, South Prairie Creek is a Class A water body, and the historical monitoring data met the Class A water quality standards. However, monitoring conducted in 2000-2001 indicates that much of lower South Prairie Creek exceeds the Class A temperature standard; therefore, a TMDL was conducted.

**Wilkeson Creek was monitored by the Muckleshoot Tribe and subsequently placed on the 303(3) list in error by comparison with the Class AA water quality standards. However, Wilkeson Creek is a Class A water body, and the historical monitoring data met the Class A water quality standards. However, monitoring conducted in 2000-2001 indicates that the mouth of Wilkeson Creek exceeds Class A standards; therefore, a TMDL was conducted.

Temperature represents the equivalent of concentration of heat within a water body. Thus, the present study evaluates and allocates the load of heat received by South Prairie Creek and its tributaries while comparing the resultant instream temperature to the water quality standards. Processes that affect water temperatures in the South Prairie Creek watershed include riparian vegetation disturbance that affects stream surface shading, reduced groundwater exchange that decreases heat exchange in the gravels, channel widening due to upstream sediment sources that increases the stream surface area exposed to solar radiation, reduced summer baseflows that reduce the volume of water available to absorb heat, and two point source discharges from wastewater treatment plants that introduce warm water. This study uses riparian shade as a surrogate measure of solar heat flux to water bodies. Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface; thus, effective shade includes interception of solar radiation by topographic features as well as vegetation.

# Background

## Geographic Setting

The South Prairie Creek watershed (Figure 1) covers 90.7 $mi^2$ (235 $km^2$) and ranges in elevation from 5,933 ft (1800 m) at Pitcher Mountain to 285 ft (87 m) above mean sea level (Mastin, 1998), spanning the Puget Lowlands and Cascades ecoregions. The river flows 21.7 miles (34.8 km) from its headwaters within the Mt. Baker-Snoqualmie National Forest near the northwest corner of Mt. Rainier National Park to its confluence with the Carbon River, itself a tributary of the Puyallup River. The South Prairie Creek watershed includes three tributaries, of which Wilkeson Creek is the largest, with a watershed of 28 $mi^2$ (73 $km^2$). Spiketon Creek, also known as Spiketon Ditch, flows to South Prairie Creek upstream of the Wilkeson Creek confluence and has a watershed area of 3.2 $mi^2$ (8.2 $km^2$). A small unnamed tributary with a watershed of 0.7 $mi^2$ (1.8 $km^2$) originates in the town of South Prairie and discharges to South Prairie Creek downstream of the town. The shape of the watershed is such that only very small tributaries other than these three enter the main stem of South Prairie Creek.

## Basin Characteristics

Climate in the basin follows patterns typical of the Puget Lowlands and Cascades ecoregions, with wet, mild winters and dry, cool summers. Mean annual average precipitation in the watershed varies from 85 in/yr (2.2 m/yr) at the higher elevations to 38 in/yr (1.0 m/yr) at the mouth (DNR, 1995; Miller et al., 1973). Most of the average annual precipitation occurs between November and April. Winter precipitation falls as rain in the lowlands and a mix of rain and snow at higher elevations.

Streamflow also varies seasonally. Highest flows occur between November and February, while the lowest flows occur in August and September, based on USGS stream gage located at the town of South Prairie (Figure 2). Average discharge for the water years[1] 1988 to 2001 is 223 cfs (6.31 $m^3$/s). Minimum 7-day average flows have ranged from 25 to 42 cfs (0.71 to 1.19 $m^3$/s).

[1] Water year 2001 refers to the period October 1, 2000 through September 30, 2001.

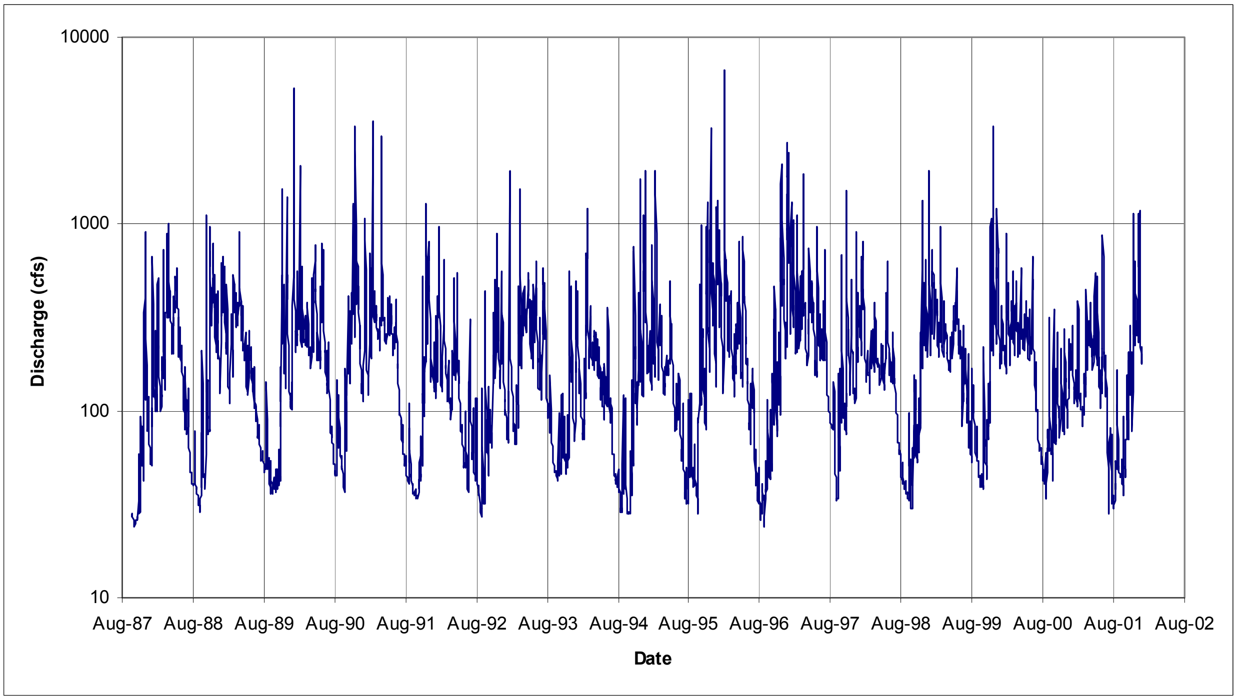



Figure 2. Historical discharge at USGS gage 12095000 on South Prairie Creek.

The watershed is composed of well compacted glacial till and stratified drift deposits. The upper watershed is characterized by steeper gradients, but the local channel slope in the lowlands study area varies from 0.03 to 0.003. The Osceola mudflow spilled into the South Prairie Creek valley near the confluence of Spiketon Creek/Ditch. The low-permeability valley bottom includes the developed areas of South Prairie, Wilkeson, Buckley, and Burnett (USDA SCS, 1979).

Current land use includes forestry operations in the higher elevations. The Mount Baker-Snoqualmie National Forest, administered by the White River Ranger District, includes 27 $mi^2$ (70 $km^2$; Mastin, 1998) of the headwaters of South Prairie Creek. The area is not included in the present modeling analysis, since no impairment has been identified. In addition, the U.S. Forest Service is required to develop forest plans under the National Forest Management Act. Private timber companies, including Plum Creek, own land within the South Prairie Creek watershed. The area falls under the jurisdiction of the Timber Fish and Wildlife (TFW) Agreement. The 1987 agreement and the subsequent Forests and Fish Report, presented to the Forest Practices Board of Washington of the Department of Natural Resources and the Governor’s Salmon Recovery Office in 1999, establish the following goals: provide compliance with the Endangered Species Act for aquatic and riparian-dependent species on non-federal forest lands, restore and maintain riparian habitat to support a harvestable fish supply, meet the requirements of the Clean Water Act, and keep the timber industry economically viable.

Two dairy facilities located near the town of South Prairie are the only commercial agriculture operations in the watershed. However, small non-commercial farms occur throughout the lower watershed.

Residential land use includes both small urban centers and rural residential parcels. Wilkeson is the largest town in the watershed, with a population of 395, based on the 2000 census. Local springs provide drinking water. The town owns and operates a wastewater treatment plant that discharges to Wilkeson Creek. South Prairie is the next largest town with a population of 332, based on the 2000 census. The town relies on local wells for drinking water and operates a wastewater treatment plant that discharges to South Prairie Creek. Buckley has a water right for 2 cfs (0.057 $m^3/s$) and diverts a portion of upper South Prairie Creek for its water supply but did not gage the volume during the study period. Buckley discharges wastewater to the adjacent White River watershed; thus, the South Prairie Creek withdrawal represents an out-of-basin transfer since the water does not return to the watershed. The Department of Social and Health Services (DSHS) shares the diversion and has a water right for 3.5 cfs (0.10 $m^3/s$) to serve the Rainier State School and Washington State University Dairy Forage Facility[2]. Burnett is the site of a large on-site wastewater demonstration project that relies on various emerging technologies (Creveling, 2002). The project replaced direct wastewater discharges to the creek. Other scattered residential developments throughout the lower watershed rely on private wells and septic systems. One septic system serving a residential property near the South Prairie wastewater treatment plant failed during the February 28, 2001 Nisqually earthquake (Pieritz, 2002). The system has been repaired. The Tacoma/Pierce County Health Department has determined that soils in the area are unsuitable for septic systems.

# Pollutant Sources

Two facilities have NPDES permits for domestic wastewater discharge, which contribute both fecal coliform bacteria and heat loads to the receiving waters. The Wilkeson wastewater treatment plant discharges to Wilkeson Creek about 4.2 mi. (6.7 km) upstream of the confluence with South Prairie Creek. The current permit limits do not include limits for discharge rate or temperature, although the facility reports both. Fecal coliform bacteria concentrations must not exceed 200/100 mL as the monthly geometric mean or 400/100 mL for a weekly geometric mean. The South Prairie wastewater treatment plant limits maximum daily inflow to the plant to 38,200 gpd (0.059 cfs or 0.0017 $m^3/s$); the permit does not limit temperature, although the facility reports effluent temperature. Fecal coliform bacteria must meet a monthly geometric mean of 200/100 mL and weekly geometric mean limit of 400/100 ml.

Nonpoint sources of fecal coliform bacteria include septic systems, dairy operations, domestic animals, and wildlife. Loads are released directly to water bodies or indirectly through subsurface loads or surface loads. These sources were quantified geographically in the data collection program by isolating the various sources.

Nonpoint sources also influence stream temperature by decreasing effective shade, reducing surface water discharge, reducing groundwater exchange, or increasing stream surface area through channel widening. Local riparian vegetation removal reduces the amount of shortwave radiation absorbed by leaves in the canopy, which increases the incident shortwave radiation to the stream. These disturbances result in elevated temperatures that propagate downstream. As the amount of water in the stream decreases, the volume of water capable of absorbing the heat

[2] The WSU facility ceased dairy operations as of July 2000 but continues farming operations.

decreases and temperature increases. Also, if the amount of groundwater discharging to surface water or the volume of mixed surface/groundwater that recirculates through the gravels decreases, surface water temperature increases. No evidence of channel widening was identified, but widening would result in higher stream surface area and more solar radiation absorbed in a given stream reach.

# South Prairie Creek
# Fecal Coliform Bacteria TMDL

## Applicable Water Quality Criteria

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, classifications, numeric criteria, and narrative standards for surface waters of the state.

South Prairie Creek discharges to the Carbon River, which is a tributary to the Class A portion of the Puyallup River. Neither South Prairie Creek nor the Carbon River are classified separately from the Puyallup River in the water quality standards. Therefore, South Prairie Creek and its tributaries are classified as Class A from the confluence with the Carbon River upstream to the Mt. Baker-Snoqualmie National Forest boundary. All streams within the National Forest are classified as Class AA. The present study focuses on the Class A portions of the South Prairie Creek watershed.

Characteristic uses for Class A (excellent) water bodies include water supply (domestic, industrial, agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, harvesting), wildlife habitat, recreation (primary-contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation. Numeric criteria for particular parameters are intended to protect designated uses.

For Class A freshwater bodies,

> *"…fecal coliform organism levels shall both not exceed a geometric mean value of 100 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL."*
>
> [WAC 173-201A-030 (2)(c)(i)(A)]

Fecal coliform bacteria, while not disease-causing organisms, have been adopted as indicator organisms for other pathogens with a fecal pathway that could impact human health. During the technical studies for South Prairie Creek, the water quality standards were under review. Potential changes included use of *E. coli* or enterococci as indicators of fecal pathogenic organisms. Therefore, *E. coli* and enterococci were included in the monitoring program. However, at the time of publication, fecal coliform bacteria remain the indicator organism on which the present TMDL is based. Appendix A includes data for all three potential indicators should the indicator organism change in the future.

## Water Quality and Resource Impairments

Data collected by Ecology under the ambient monitoring program at station 10F090 (3.8 miles, or 6.1 km from the mouth; station SPCB4 of present study) from October 1992 through

September 1993 have a geometric mean concentration of 133/100 ml. Four of 12 samples (33%) exceeded 200/100 ml. Therefore, South Prairie Creek did not meet either of the two parts of the fecal coliform bacteria standard. The impaired use is recreation (primary-contact recreation, sport fishing, boating, aesthetic enjoyment).

Additional sampling conducted as part of the present study shows that South Prairie Creek downstream of station 10F090, Spiketon Creek/Ditch, and the unnamed tributary near the town of South Prairie (stations T1 and T1ID) do not meet water quality standards. Figure 3 summarizes recent fecal coliform monitoring data. Table 2 describes monitoring locations.

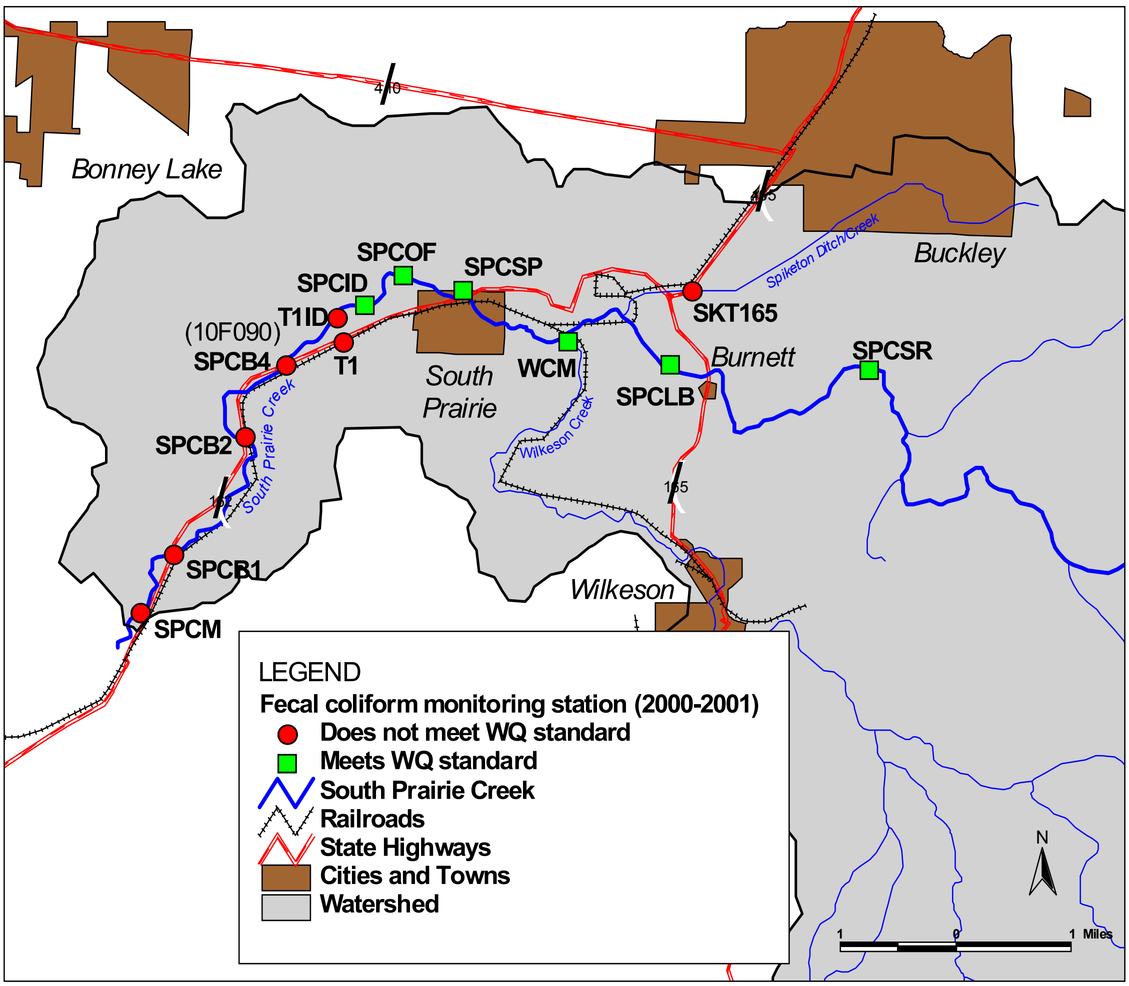



Figure 3. Stations not meeting the fecal coliform water quality standard.

Table 2. Monitoring locations for the South Prairie Creek watershed bacteria study.

| ID | Water Body | Description |
|---|---|---|
| SPCM | South Prairie Creek | At mouth, from South Prairie Creek Road |
| SPCB1 | South Prairie Creek | At Route 162, first bridge north of Carbon River |
| SPCB2 | South Prairie Creek | At Route 162, second bridge north of Carbon River |
| SPCB4 | South Prairie Creek | At Route 162, fourth bridge north of Carbon River |
| SPCID | South Prairie Creek | At Inglin Dairy bridge |
| SPCOF | South Prairie Creek | At South Prairie wastewater treatment plant outfall; access from road by cabinet factory |
| SPCSP | South Prairie Creek | At South Prairie; access from fire station |
| SPCLB | South Prairie Creek | At Lower Burnett Road, downstream of Route 165 bridge |
| SPCSR | South Prairie Creek | At Spiketon Road, south of Buckley |
| T1 | Unnamed tributary | At Route 162 culvert for ditch from South Prairie |
| T1ID | Unnamed tributary | At mouth of ditch from South Prairie; access from Inglin Dairy |
| WCM | Wilkeson Creek | At mouth; access from KC Crusaders Paintball |
| SKTM | Spiketon Creek/Ditch | At mouth; access from Lower Burnett Road |

## Seasonal Variation

Clean Water Act Section 303(d)(1)(C) requires that TMDLs “be established at a level necessary to implement the applicable water quality standards with seasonal variations….” The current regulation also states that determination of “TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters” [40 CFR 130.7(c)(1)]. Fecal coliform bacteria concentrations and loads show seasonal variations, particularly in the lower watershed. Higher fecal coliform loads tend to coincide with wet winter conditions (Figure 4); however, elevated concentrations occur throughout the year and at a range of discharges. There was no statistically significant difference in fecal coliform bacteria concentrations in dry and wet conditions[3] (P=0.646).

The non-growing season (November through April) tends to coincide with wet-weather conditions in the Puget Lowlands. For South Prairie Creek main stem stations, concentrations are higher during the non-growing season than the growing season. At other stations, the growing season concentrations are greater than the non-growing season levels. Therefore, the load allocations include both growing season and non-growing season reductions.

[3] Dry is defined as <0.1 in of rain on the day of sampling or <0.2 in rain in the three days preceding. Wet conditions occur if at least 0.1 in fell on the day of sampling and at least 0.2 in fell in the previous days. Days where one condition is met but not the other were not included in the analysis.

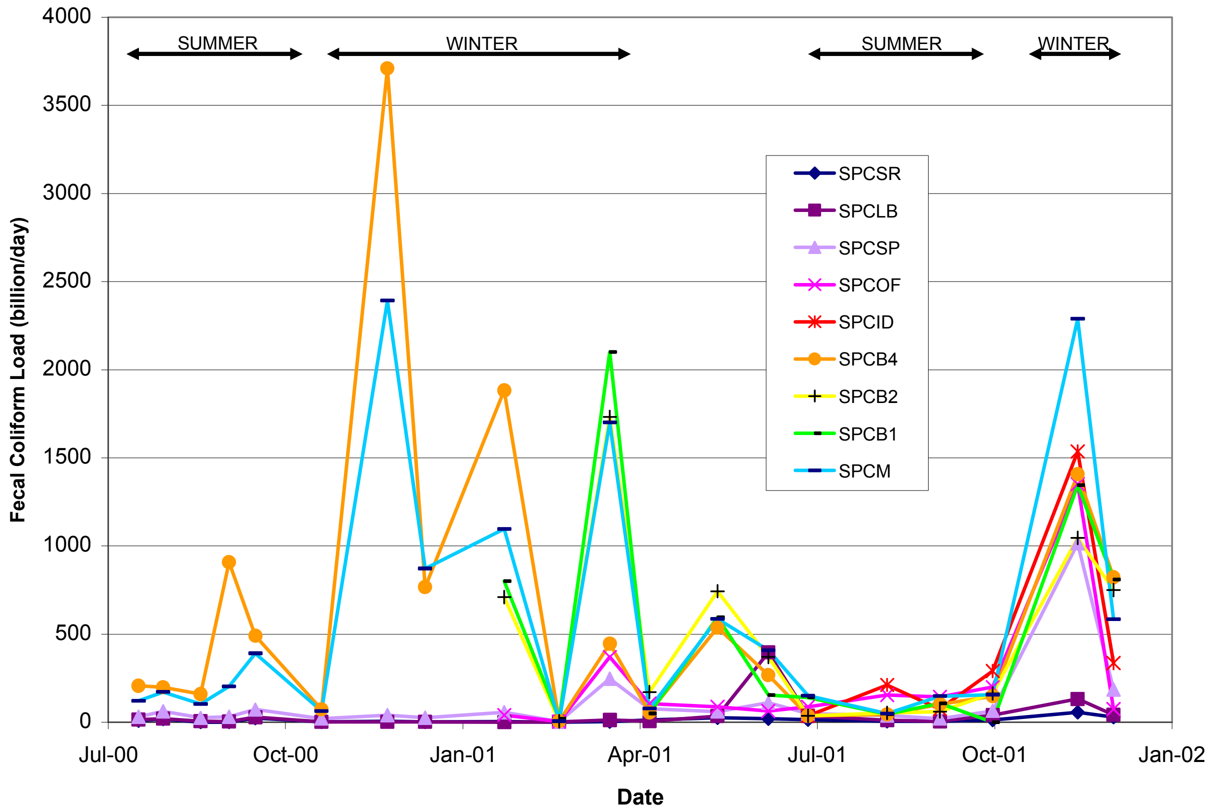



Figure 4. Time series of instantaneous fecal coliform loads at South Prairie Creek monitoring stations.

# Technical Analyses

The technical analyses are based on historical and recent field and laboratory data collection, statistical analysis, and statistical modeling. The Quality Assurance Project Plans (Roberts 2000 and 2001) describe the data collection program and methods.

## Data Used in the Analysis

Water quality samples were collected and analyzed for fecal coliform twice monthly or monthly from July 2000 through December 2001. Nine monitoring stations were established over the 10.4-mi (16.8-km) study area to isolate potential sources. Instantaneous flows were measured at all accessible and appropriate stations using standard velocity-area methods (Ecology, 1993). The U.S. Geological Survey (USGS) stream gage at the town of South Prairie provides a continuous flow record since October 1, 1987. Appendix A includes all monitoring data.

Data were compiled and analyzed using Microsoft Excel®. Instantaneous loads were calculated using instantaneous flow measurements where available. Where not available, flows were calculated using relationships with the USGS gage site or other instantaneous sites. Loads are analyzed as billion fecal coliform per day.

## Critical Conditions

Elevated fecal coliform levels occur throughout the year and under different flow regimes. Critical conditions vary by station, as described above. Therefore, the TMDL analysis includes load reduction targets for both the growing season and the non-growing season.

## Statistical Analysis

Sources of bacteria were identified and quantified by calculating the differential load entering a reach as the difference between the downstream and upstream loads using the pooled datasets. Both concentrations and loads were compared using one-tailed t-tests to identify whether loads at downstream stations were significantly greater than loads at the upstream station. Significant load increases ($\alpha$=0.05) occurred between stations SPCSP and SPCB4, and between SPCSP and SPCOF (Figure 5). No significant load increases occurred downstream of SPCB4.

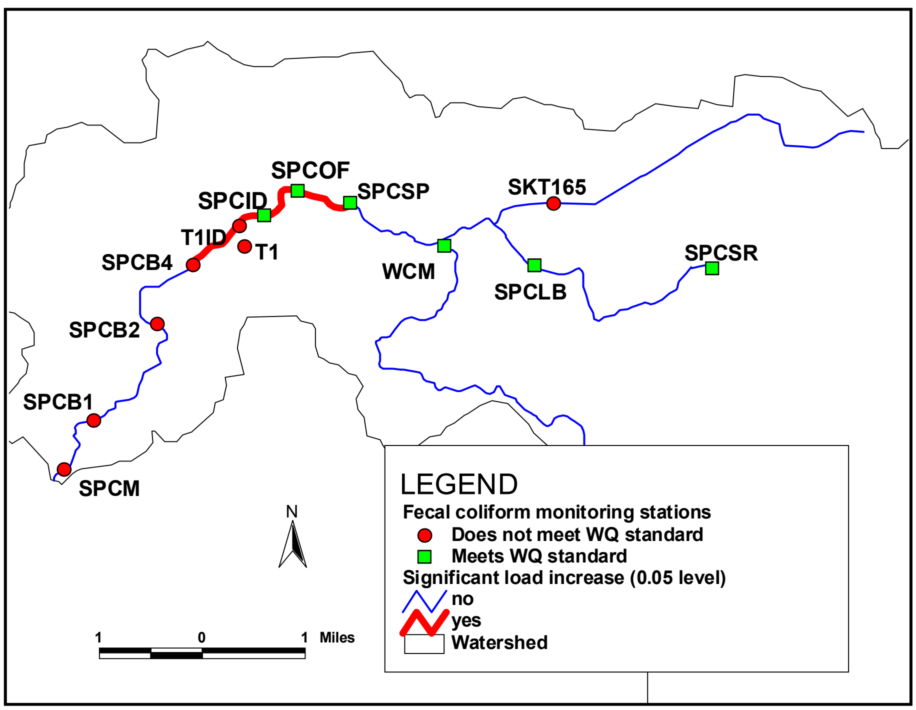



Figure 5. Significant increases in loads.

## Modeling Approach

The modeling approach uses the statistical rollback method to determine the load reduction necessary to achieve the fecal coliform water quality standard in South Prairie Creek, Spiketon

Creek/Ditch, and the unnamed tributary at the town of South Prairie. The statistical rollback method (Ott, 1995) has been used by Ecology to determine the necessary reduction for both the geometric mean value (GMV) and 90$^{th}$ percentile bacteria concentration (Joy, 2000) to meet water quality standards. Compliance with the most restrictive of the dual fecal coliform criteria determines the bacteria reduction needed. Fecal coliform sample results for each site in this study were found to follow lognormal distributions, and the 90$^{th}$ percentile was calculated as the antilog of the mean of the log-transformed data plus 1.28 times the standard deviation of the log-transformed data.

The rollback method uses statistical characteristics of a known data set to predict the statistical characteristics of a data set that would be collected after pollution controls have been implemented and maintained. In applying the rollback method, the target fecal coliform GMV and the target 90$^{th}$ percentile are set to the corresponding water quality standard. The reduction needed for each target value to be reached is determined. The rollback factor, $f_{rollback}$, is calculated as

$$f_{rollback} = \text{minimum } \{ (100/\text{sample GMV}), (200/\text{sample } 90^{th} \text{ percentile}) \}$$

The percent reduction ($f_{reduction}$) needed is

$$f_{reduction} = (1 - f_{rollback}) \text{ x } 100\%$$

which is the percent reduction that allows both GMV and 90$^{th}$ percentile target values to be met. The result is a revised target value for both the GMV or the 90$^{th}$ percentile. In most cases, a reduction of the 90$^{th}$ percentile is needed and application of this reduction factor to the study GMV yields a target GMV that is usually less (i.e., more restrictive) than the water quality criterion. The 90$^{th}$ percentile is used as an equivalent expression to the "no more than 10%" criterion found in the second part of the water quality standards for fecal coliform bacteria. The reduction factors and description of sources are included under Load Allocations.

## Loading Capacity

The loading capacity is the maximum load that can be assimilated by the receiving waters without violating water quality standards. Because fecal coliform has a two-part water quality standard for concentration, the load capacity also has two parts:

$$LC_{GMV} = Q \bullet 100/100 \text{ mL} \bullet f_{convert}$$
$$LC_{90\%ile} = Q \bullet 200/100 \text{ mL} \bullet f_{convert}$$

where LC is the load capacity in billion fecal coliform per day, Q is discharge in cfs, and $f_{convert}$ is 0.0245 to convert cfs • #/100 mL to billion fecal coliform per day. Load allocations are based on the reduction factors discussed above. Figure 6 compares current conditions with the loading capacity for geometric mean and 90$^{th}$ percentile fecal coliform bacteria concentrations.

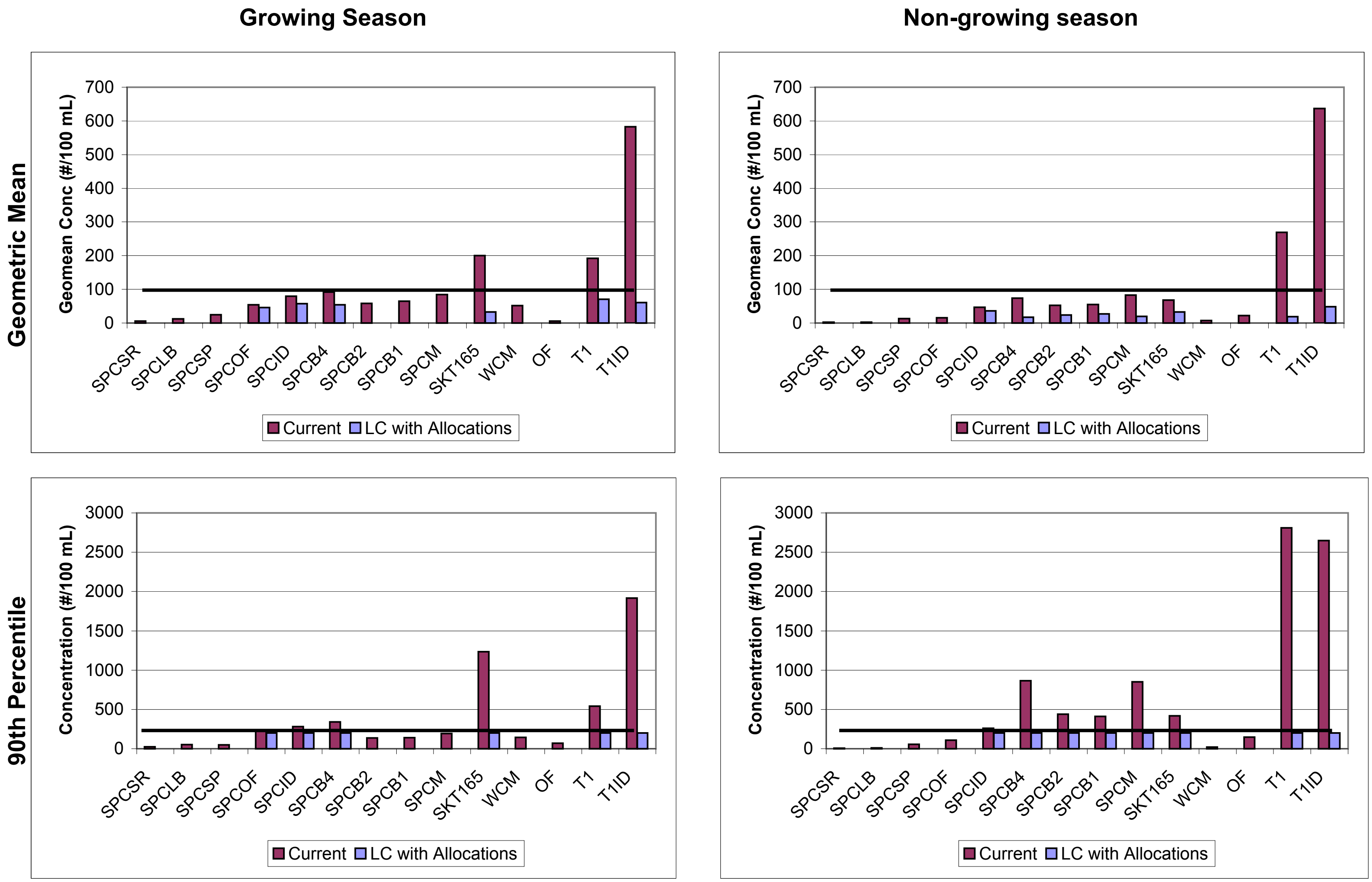



Figure 6. Fecal coliform bacteria loading capacity of South Prairie Creek represented as concentration.

## Load Allocations

Load allocations are set for South Prairie Creek downstream of the town of South Prairie (station SPCSP), Spiketon Creek/Ditch, and the unnamed tributary from the town of South Prairie using the rollback method to determine the reduction factors necessary to meet both parts of the water quality standard for fecal coliform. Reduction factors are calculated for two periods, growing season (May through October) and non-growing season (November through April), and load allocations are set for both.

All load reduction factors are summarized in Table 3. Station reduction factors include all upstream reductions. The differential reduction in bacteria load in a reach is the downstream station reduction factor minus the upstream station reduction factor. If the upstream monitoring station requires a greater load reduction, then the differential load reduction at the downstream station may by 0%, even though the station exceeds water quality standards. In this case, the upstream source reduction should result in achieving water quality standards at the downstream station. For example, if the loads reaching South Prairie Creek between stations SPCOF and SPCB4 are reduced by 41% in the growing season and 77% in the non-growing season, the downstream reaches should meet water quality standards without additional load reductions, unless additional sources commence. The Spiketon Creek reduction factor includes the entire subwatershed. Wilkeson Creek meets the bacteria standard and does not require load allocations. The South Prairie wastewater treatment plant outfall also met the bacteria standard at the point of discharge. The unnamed tributary did not meet the water quality standard at either of two monitoring locations. The reduction factor at the downstream station (T1ID at the mouth) are greater than the reduction factor for the upstream station (T1 at State Route 162). Thus, while loads must be reduced 63% in the growing season upstream of SR 162, additional load reductions are necessary between T1 and T1ID for a total of 90% reduction in bacteria levels for the entire tributary to meet water quality standards. Table 4 presents the data on which the load reductions necessary during the growing season are based, while Table 5 presents the data for load reductions during the non-growing season. Several stations meet the water quality standards during the growing season but not during the non-growing season.

Table 3. Load reduction factors summary by season.

| ***Station*** | ***Growing Season*** | | ***Non-growing Season*** | |
|---|---|---|---|---|
| | Total load reduction at station | Differential load reduction upstream of station | Total load reduction at station | Differential load reduction upstream of station |
| ***Main Stem of South Prairie Creek*** | | | | |
| SPCSR | NA | NA | NA | NA |
| SPCLB | NA | NA | NA | NA |
| SPCSP | NA | NA | NA | NA |
| SPCOF | **14%** | 14% | NA | NA |
| SPCID | **28%** | **28% - 14% = 14%** | **23%** | **23%** |
| SPCB4 | **41%** | **41% - 28% = 13%** | **77%** | **77% - 23% = 54%** |
| SPCB2 | NA | NA | **54%** | 54% - 77% < 0% |
| SPCB1 | NA | NA | **52%** | 52% - 77% < 0% |
| SPCM | NA | NA | **77%** | 77% - 77% < 0% |
| ***Tributaries to South Prairie Creek*** | | | | |
| Spiketon Creek/Ditch (SKT165) | **84%** | **84%** | **52%** | **52%** |
| Wilkeson Creek (WCM) | NA | NA | NA | NA |
| SP WWTP outfall | NA | NA | NA | NA |
| Unnamed tributary at SR162 (T1) | **63%** | **63%** | **93%** | **93%** |
| Unnamed tributary at mouth (T1ID) | **90%** | **90% - 63% = 27%** | **92%** | 92% - 93% < 0% |

NA: not applicable; station meets water quality criterion

Table 4. Load reductions necessary to meet water quality standards during the growing season (May through October). Bold values exceed water quality standards.

| Station | Number of Samples | Meets Std? | Geo-mean | 90th %ile | $f_{rollback}$ for GMV (target to meet std) | $f_{rollback}$ for 90th %ile (target to meet std) | $f_{reduction}$ (reduction to meet std) | Target geo-mean | Target 90%ile |
|---|---|---|---|---|---|---|---|---|---|
| ***Main Stem of South Prairie Creek*** | | | | | | | | | |
| SPCSR | 12 | YES | 6 | 24 | NA | NA | NA | | |
| SPCLB | 12 | YES | 12 | 54 | NA | NA | NA | | |
| SPCSP | 12 | YES | 25 | 49 | NA | NA | NA | | |
| SPCOF | 6 | YES | 54 | **234** | NA | 86% | **14%** | 46 | 200 |
| SPCID | 4 | YES | 80 | **280** | NA | 72% | **28%** | 57 | 200 |
| SPCB4 | 12 | NO | 92 | **340** | NA | 59% | **41%** | 54 | 200 |
| SPCB2 | 6 | YES | 58 | 138 | NA | NA | NA | | |
| SPCB1 | 5 | YES | 64 | 142 | NA | NA | NA | | |
| SPCM | 12 | YES | 84 | 192 | NA | NA | NA | | |
| ***Tributaries to South Prairie Creek*** | | | | | | | | | |
| SKT165 | 12 | NO | **200** | **1234** | 50% | 16% | **84%** | 32 | 200 |
| WCM | 12 | YES | 52 | 145 | NA | NA | NA | | |
| OF | 6 | YES | 6 | 72 | NA | NA | NA | | |
| T1 | 6 | NO | **192** | **542** | 52% | 37% | **63%** | 71 | 200 |
| T1ID | 4 | NO | **583** | **1916** | 17% | 10% | **90%** | 61 | 200 |

NA: not applicable; station meets water quality criterion

Table 5. Load reductions necessary to meet water quality standards during the non-growing season (November through April). Bold values exceed water quality standards.

| Station | Number of Samples | Meets Std? | Geo-mean | 90th %ile | $f_{rollback}$ for GMV (target to meet std) | $f_{rollback}$ for 90th %ile (target to meet std) | $f_{reduction}$ (reduction to meet std) | Target geo-mean | Target 90%ile |
|---|---|---|---|---|---|---|---|---|---|
| ***Main Stem of South Prairie Creek*** | | | | | | | | | |
| SPCSR | 8 | YES | 2 | 7 | NA | NA | NA | | |
| SPCLB | 8 | YES | 2 | 9 | NA | NA | NA | | |
| SPCSP | 8 | YES | 13 | 58 | NA | NA | NA | | |
| SPCOF | 6 | YES | 16 | 110 | NA | NA | NA | | |
| SPCID | 2 | NO | 46 | **259** | NA | 77% | **23%** | 36 | 200 |
| SPCB4 | 8 | NO | 74 | **865** | NA | 23% | **77%** | 17 | 200 |
| SPCB2 | 6 | NO | 52 | **439** | NA | 46% | **54%** | 24 | 200 |
| SPCB1 | 6 | NO | 55 | **413** | NA | 48% | **52%** | 27 | 200 |
| SPCM | 8 | NO | 83 | **851** | NA | 23% | **77%** | 19 | 200 |
| ***Tributaries to South Prairie Creek*** | | | | | | | | | |
| SKT165 | 8 | NO | 68 | **420** | NA | 48% | **52%** | 33 | 200 |
| WCM | 8 | YES | 7 | 22 | NA | NA | NA | | |
| OF | 5 | YES | 22 | 149 | NA | NA | NA | | |
| T1 | 6 | NO | **270** | **2809** | 37% | 7% | **93%** | 19 | 200 |
| T1ID | 2 | NO | **637** | **2649** | 16% | 8% | **92%** | 48 | 200 |

NA: not applicable; station meets water quality criterion

From Table 3, loads entering South Prairie Creek between SPCSP and SPCB4 should be reduced by 41% in the growing season and 77% in the non-growing season. Slightly greater reduction is required during the non-growing season to meet water quality standards for that period because concentrations are greater. Potential sources include stormwater runoff from the town of South Prairie via the unnamed tributary (sampled at stations T1 and T1ID), the South Prairie wastewater treatment plant, failed septic systems, wildlife, or discharges from the dairy.

The unnamed tributary enters South Prairie Creek within this reach and requires significant load reductions to meet water quality standards before discharging to South Prairie Creek. Upstream of Route 162, as identified by station T1, the tributary fecal coliform loads should be reduced by 81% overall, with slightly higher reductions necessary during the non-growing season and during high-flow conditions. The mouth of the tributary, identified as station T1ID, requires an overall reduction of 90%, which is required in both the growing and non-growing seasons and at both high- and low-flow conditions. Load reductions achieved upstream of Route 162 (station T1) will reduce loads at the mouth (station T1ID), but additional load reductions are necessary between Route 162 and the mouth of the tributary. Upstream of Route 162, land use is moderately dense residential development, with some commercial. Between Route 162 and the mouth, land use is agricultural with limited rural residential.

The unnamed tributary originates in the town of South Prairie and conveys groundwater and stormwater. The tributary had very high concentrations of fecal coliform bacteria during the 2001 monitoring program. Flow was not measured in the very small ditch. For a typical condition of a trapezoidal channel with 1:2 side slopes, bottom width of 3 ft, flow depth of 0.5 ft, channel slope of 0.005, and Manning's roughness of 0.35, Manning's equation estimates a flow of 0.3 cfs (0.008 $m^3/s$):

$$Q = A * (1.49/n) * R^{2/3} S^{1/2},$$

where Q is discharge in cfs, A is cross-sectional area in $ft^2$, n is Manning's roughness, R is the hydraulic radius (equal to the cross-sectional area divided by the wetted perimeter), and S is channel slope. Peak flows were estimated to be on the order of 1 cfs (0.03 $m^3/s$). The highest concentration was 2200/100 ml; with a flow of 1 cfs, the tributary may have contributed on the order of 50 billion fecal coliform/day, which could include failing septic system contributions. However, the average difference in loads between these two stations was 500 billion fecal coliform per day; therefore, at most, T1 represents 10% of the incremental load to South Prairie Creek between SPCSP and SPCB4 and is not the only significant source.

Samples collected from the South Prairie wastewater treatment plant during the present study met the water quality standards with a geometric mean of 9/100 mL and a maximum of 80/100 mL (12 samples), without considering a mixing zone. The plant submits monthly reports of daily monitoring data. Table 6 presents low, medium, and high estimates of daily loads for each month of the monitoring program. The highest single-day load from the plant was 1.1 billion fecal coliform/day on 9/19/00, a monitoring day along the creek. The instantaneous load upstream at SPCSP was 50 billion fecal coliform/day, while the load downstream at SPCB4 was 300 billion fecal coliform/day. The treatment plant contributed 0.4% of the differential load upstream of SPCB4 and is responsible for only a small portion of the increase.

Table 6. South Prairie wastewater treatment plant fecal coliform load estimates.

| Month | Low [1] ($10^9$ fcb/day) | Medium [2] ($10^9$ fcb/day) | High [3] ($10^9$ fcb/day) |
|---|---|---|---|
| Jul-00 | 0.003 | 0.006 | 0.036 |
| Aug-00 | 0.003 | 0.029 | 0.123 |
| Sep-00 | 0.002 | **0.072** | **1.140** |
| Oct-00 | 0.002 | 0.002 | 0.003 |
| Nov-00 | 0.002 | 0.005 | 0.022 |
| Dec-00 | 0.004 | 0.012 | 0.079 |
| Jan-01 | 0.002 | 0.005 | 0.022 |
| Feb-01 | 0.002 | 0.004 | 0.014 |
| Mar-01 | 0.003 | 0.017 | 0.099 |
| Apr-01 | 0.002 | 0.003 | 0.006 |
| May-01 | 0.001 | 0.007 | 0.323 |
| Jun-01 | **0.005** | 0.028 | 0.300 |
| Jul-01 | 0.002 | 0.005 | 0.121 |
| Aug-01 | 0.002 | 0.003 | 0.010 |
| Sep-01 | 0.002 | 0.005 | 0.016 |
| Oct-01 | 0.002 | 0.002 | 0.002 |
| Nov-01 | 0.002 | 0.005 | 0.044 |
| Dec-01 | <0.001 | <0.001 | <0.001 |

1 Monthly average flow x min weekly fecal coliform concentration
2 Monthly average flow x geomean weekly fecal coliform concentration
3 Monthly average flow x max weekly fecal coliform concentration

With the exception of the failure during the Nisqually earthquake, no septic system failures have been located. However, the Tacoma/Pierce County Health District does not believe the soils in the South Prairie Creek valley are suitable for septic systems. At least ten homes in the area are served by septic systems. Assuming a per capita contribution of 2 billion fecal coliform/day (Metcalf and Eddy, 1991) and four people per household, failing septic systems could contribute 8 billion fecal coliform/day/system, or as much as 80 billion fecal coliform/day for ten homes. Thus, failing septic systems could contribute a significant portion of the load between SPCSP and SPCB4.

A synoptic survey, conducted in August 2001, found no other inflows with elevated fecal coliform concentrations. Several pipes and seeps were located between SPCSP and SPCB4 and sampled.

Wildlife contributions were not quantified explicitly in the study. However, using literature values for gull contributions of 0.1 billion fecal coliform/day (Gould and Fletcher, 1978; Nixon and Oviatt, 1973), 2,500 gulls would be necessary to contribute the differential fecal coliform load between SPCSP and SPCB4. There is no evidence that wildlife frequent this reach more than other reaches. Due to the level of development, wildlife are likely less prevalent between SPCSP and SPCB4.

Using literature values for cow contributions of 5.4 billion fecal coliform/day/cow (Metcalf and Eddy, 1991), waste from 46 cows would be sufficient to account for the differential load. While no direct discharges of waste from the dairy to South Prairie Creek were identified, field applications of manure were witnessed, and the dairy waste tank abuts South Prairie Creek. Both potential transport pathways could account for a significant proportion of the highly concentrated source entering South Prairie Creek between SPCSP and SPCB4. Either pathway could account for the intermittent nature of very high loads.

Load reductions achieved between SPCSP and SPCB4 will decrease the loads downstream of SPCB4. Travel time estimates were developed during low-flow conditions in 2001, which represent the slowest transport conditions over the year. Travel time from SPCSP to the mouth varies from 5 to 10 hours at a discharge of 40 cfs, and will be higher for higher flow rates. Therefore, there is little time for significant die-off to occur in this reach, meaning that upstream loads are not significantly attenuated. Unless the high bacteria loads masked low-level sources downstream of SPCB4, load reductions achieved between SPCSP and SPCB4 will cause downstream reaches to meet the water quality standards as well.

## Wasteload Allocations

Wilkeson Creek met the fecal coliform bacteria water quality standard during the 2000-2001 monitoring period. Therefore, Wilkeson wastewater treatment plant permit limits should remain at the current level of 200/100 mL for a monthly geometric mean and 400/100 mL for a weekly geometric mean, which are technology-based limits (Pieritz, personal communication, 2003). No further reduction in wasteload allocation is recommended, given that the plant contributes <1% of the load increase in the system, and the current permit limits represent the wasteload allocation for the Wilkeson wastewater treatment plant.

The South Prairie wastewater treatment plant discharges to an impaired section of South Prairie Creek. Therefore, the permit limits will be set to 100/100 mL for a monthly geometric mean and 200/100 mL for a weekly geometric mean (Pieritz, personal communication, 2003). These are technology-based limits for discharges to impaired waters that permit managers are to use until a TMDL is completed. Nonpoint sources contribute the vast majority of the bacteria load to South Prairie Creek. The TMDL submittal report to EPA, which will be based on the present technical report, must include reasonable assurance that implementation of nonpoint source management practices will occur and will reduce the bacteria load such that the creek meets the fecal coliform standard. Where reasonable assurance is not met, "the entire load reduction must be assigned to point sources," (EPA, 1991), meaning that point sources cannot discharge any bacteria load. This analysis recommends no additional reductions in the wasteload allocations, given that the plant contributes <1% of the load increase between stations SPCSP and SPCB4.

## Summary of Load and Wasteload Allocations

Figure 7 compares the current conditions to the nonpoint source loading allocation and point source wasteload allocation for South Prairie Creek for the $90^{th}$ percentile condition[4]. Current conditions exceed water quality standards, which is the loading capacity. The nonpoint load reductions discussed above will result in the load allocations shown. The point sources (shown multiplied by 10 or 100 to be visible in the figures) contribute small loads relative to the nonpoint sources, without considering die-off of the bacteria downstream of the discharge.

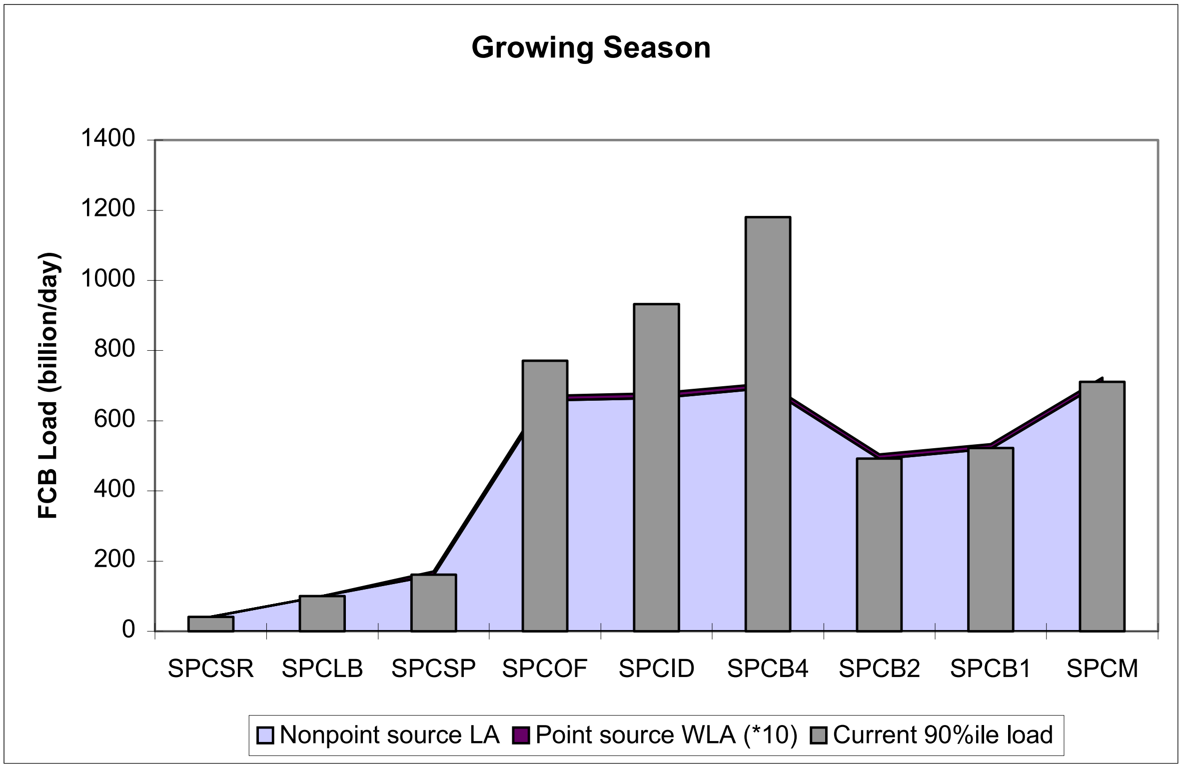
## Margin of Safety

A margin of safety to account for scientific uncertainty must be considered in the TMDL in order for wasteload and load allocations to remain protective. The margin of safety for this TMDL is implicit; it is contained within conservative assumptions used to develop the TMDL. The rollback method assumes that the variance of the post-management data set will be equivalent to the variance of the pre-management data set. As pollution sources are managed, the frequency of high fecal coliform values is likely to decrease, which should reduce the variance and $90^{th}$ percentile of the post-management condition. Finally, differential reduction factors do not take into account bacterial decay.

## Recommendations for Monitoring

To determine the success of fecal coliform control strategies, regular monitoring is recommended. Because stations SPCSP and upstream met the bacteria standards, SPCSP should be the upstream extent of regular monitoring. At a minimum, ten sites (SPCSP, SPCOF, SPCID, SPCB4, SPCB2, SPCB1, SPCM, SKTM, T1, and T1ID) should be monitored.

[4] Instream loads are based on average flows estimated for the growing and nongrowing seasons, while wastewater treatment plant wasteload allocations are based on peak monthly flows from the period of record of the DMRs.



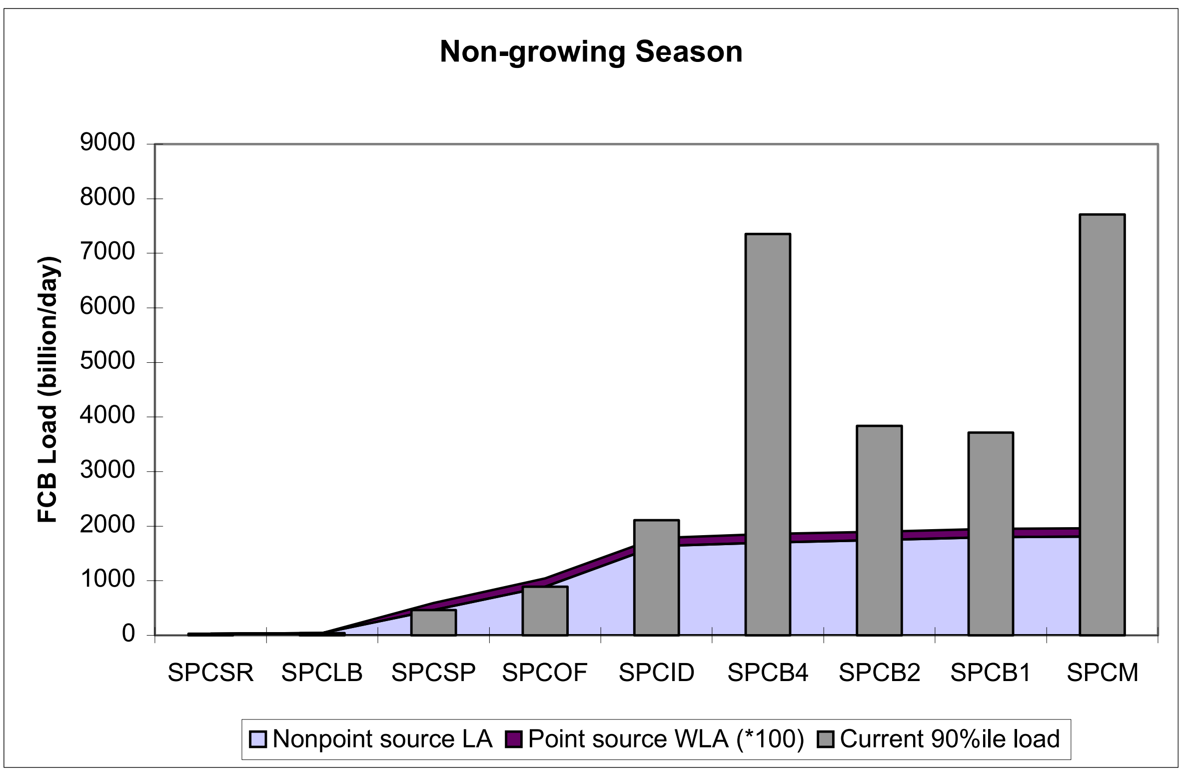




Figure 7. Current and allocated bacteria loads along South Prairie Creek. Point sources are multiplied by 10 and 100 to be visible in the charts.

# South Prairie Creek Temperature TMDL

## Applicable Water Quality Criteria

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, classifications, numeric criteria, and narrative standards for surface waters of the state.

South Prairie Creek discharges to the Carbon River, which is a tributary to the Class A portion of the Puyallup River. Neither South Prairie Creek nor the Carbon River are classified separately from the Puyallup River in the water quality standards. Therefore, South Prairie Creek and its tributaries are classified as Class A to the Mt. Baker-Snoqualmie National Forest boundary. All streams within the National Forest are classified as Class AA. The present study focuses on the Class A portions of the South Prairie Creek watershed.

Characteristic uses for Class A (excellent) water bodies include water supply (domestic, industrial, agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, harvesting), wildlife habitat, recreation (primary-contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation. Numeric criteria for particular parameters are intended to protect designated uses.

For Class A freshwater bodies,

> *"Temperature shall not exceed 18.0°C … due to human activities. When natural conditions exceed 18.0°C … no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C."*
>
> [WAC 173-201A-030 (2)(c)(iv)]

During critical periods, natural conditions may exceed the numeric temperature criteria mandated by the water quality standards. In these cases, the antidegradation provisions of those standards apply:

> *"Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria."*
>
> [WAC 173-201A-070 (2)]

Surface water temperatures reflect the heat load to a given water body. Therefore, the South Prairie Creek watershed temperature TMDL is based on heat, considered a pollutant under Section 502(6) of the Clean Water Act. Heat loads are modeled as point sources from the wastewater treatment plants, distributed sources from groundwater inflows, and incoming solar radiation to South Prairie Creek and its tributaries. Factors that affect solar radiation heat loads include topographic shade (from adjacent hillslopes), riparian shade (from vegetation), stream surface area and volume, and groundwater exchange.

## Water Quality and Resource Impairments

Data collected by the Muckleshoot Indian Tribe in 1997 at a location upstream of SPCSR peaked at 16.5°C but did not exceed the Class A water quality standard of 18°C. The creek was placed on the 303(d) list in error, based on comparison with the Class AA standards. However, monitoring indicates that all of South Prairie Creek from the town of South Prairie downstream exceeds 18°C during the 2000-2001 study period. Figure 8 summarizes the 2001 (warmest) temperature monitoring data for South Prairie Creek. Table 7 describes the monitoring locations.

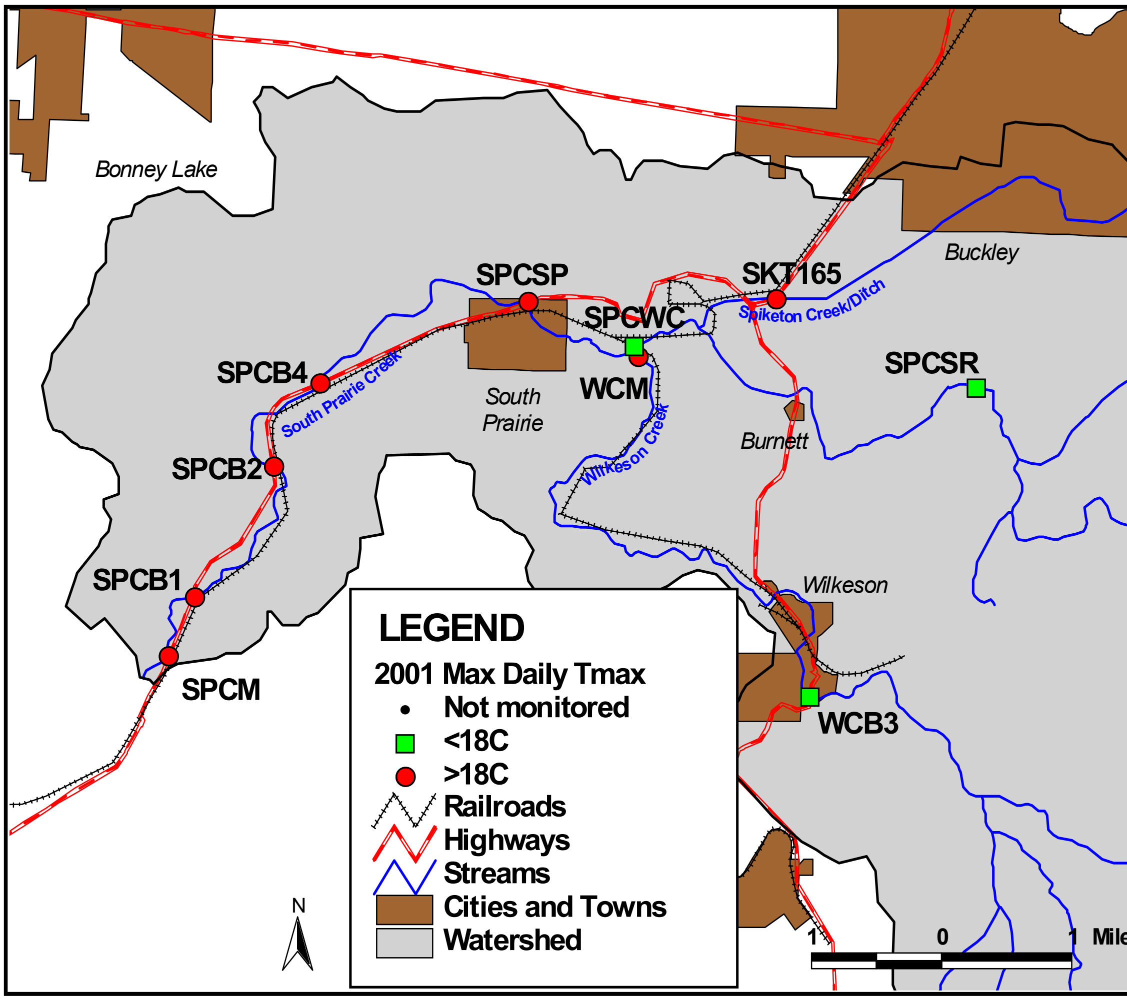



Figure 8. Comparison of Ecology temperature monitoring results along South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch to 18°C temperature standard from 2001 monitoring.

Table 7. Monitoring locations for the South Prairie Creek watershed temperature study.

| ID | Water Body | Description |
|---|---|---|
| SPCM | South Prairie Creek | At mouth, from South Prairie Creek Road |
| SPCB1 | South Prairie Creek | At Route 162, first bridge north of Carbon River |
| SPCB2 | South Prairie Creek | At Route 162, second bridge north of Carbon River |
| SPCB4 | South Prairie Creek | At Route 162, fourth bridge north of Carbon River |
| SPCSP | South Prairie Creek | At South Prairie; access from fire station |
| SPCWC | South Prairie Creek | At Wilkeson Creek confluence near train trestle; access through KC Crusaders Paintball |
| SPCSR | South Prairie Creek | At Spiketon Road, south of Buckley |
| WCM | Wilkeson Creek | At mouth; access from KC Crusaders Paintball |
| WCB3 | Wilkeson Creek | Upstream of town of Wilkeson, third bridge |
| SKT165 | Spiketon Creek/Ditch | At Route 165 culvert |

The Muckleshoot Indian Tribe also monitored two locations in the Wilkeson Creek watershed (including Gale Creek). The downstream location peaked at 17.1°C but did not exceed the Class A water quality standard of 18°C. The creek was placed on the 303(d) list in error, based on comparison with the Class AA standards. The upstream location peaked at 19.0°C and exceeded the Class A water quality standards. The upstream area is owned by Plum Creek Timber Company, Inc. and falls under the jurisdiction of the TFW Agreement. Monitoring conducted under the present study (Figure 10) indicates that while Wilkeson Creek met the 18°C standard at both locations in 2001, the station at the mouth (WCM) exceeded the standard in 2000.

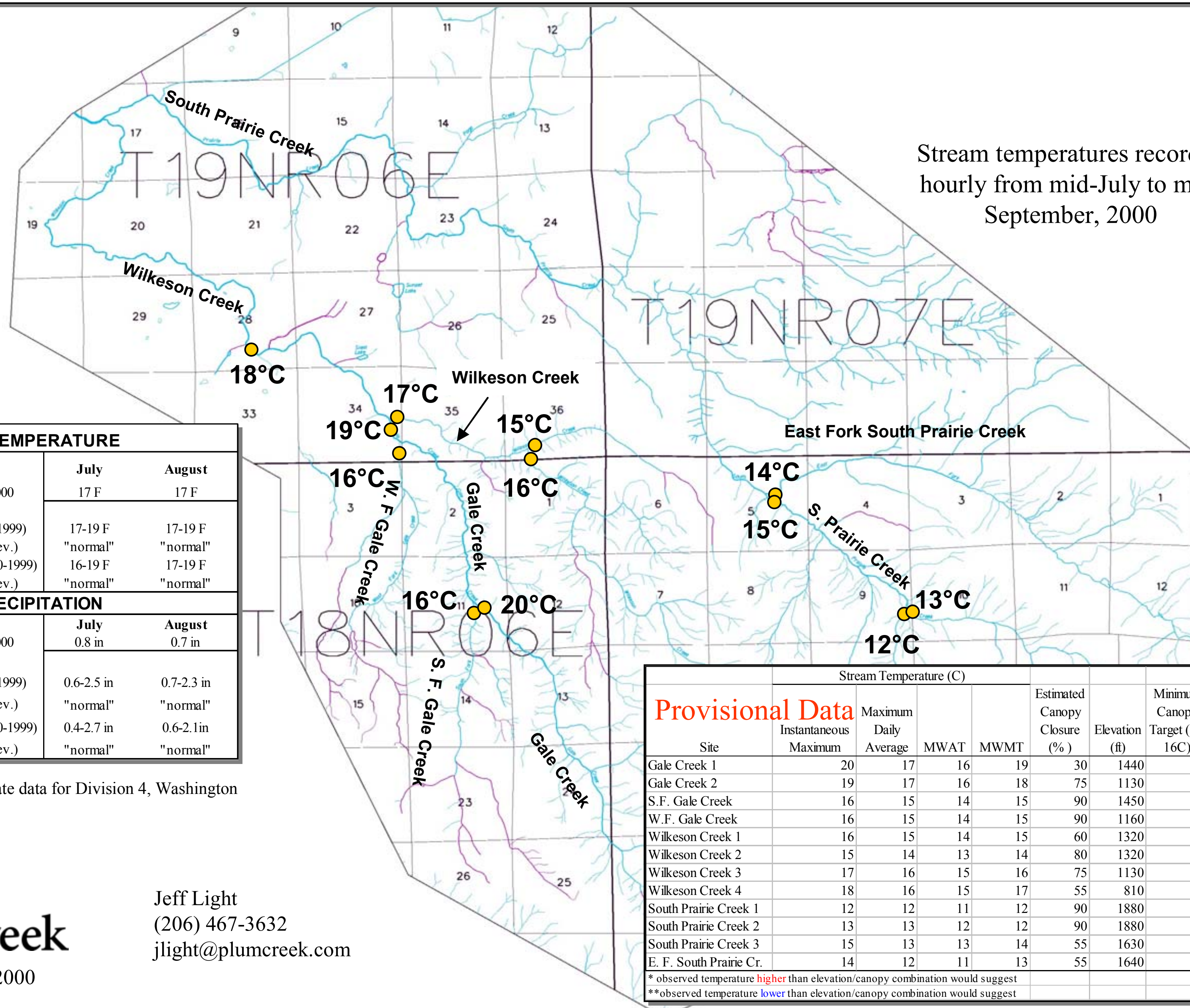
Plum Creek recorded temperature continuously at numerous stations in the upper reaches of South Prairie Creek and Wilkeson/Gale Creek in 2000. As shown in Figure 9, although the four sites in upper South Prairie Creek met the 18°C standard, two sites on Gale Creek exceeded the standard. The region falls under the jurisdiction of the TFW Agreement.

In addition, Ecology monitored the temperature of Spiketon Creek/Ditch in 2000 and 2001. Results in Figure 8 indicate that Spiketon Creek/Ditch peaked at 19.7°C in 2001 and does not meet the 18°C Class A temperature standard.

## Seasonal Variation

Clean Water Act Section 303(d)(1)(C) requires that TMDLs "be established at a level necessary to implement the applicable water quality standards with seasonal variations…." The current regulation also states that determination of "TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters" [40 CFR 130.7(c)(1)]. Finally, Section 303(d)(1)(D) suggests that the "total maximum daily thermal load required to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife … shall take into account the normal water temperatures, flow rates, seasonal variations, existing sources of heat input, and the dissipative capacity of the identified waters…."

Figure 9.
Plum Creek Timber Company temperature monitoring in the South Prairie Creek watershed (2000).




Stream temperatures recorded hourly from mid-July to mid-September, 2000

**AIR TEMPERATURE**

| | July | August |
|---|---|---|
| 2000 | 17 F | 17 F |
| Ten-Year Average (1990-1999) (mean +- 1 Std. Dev.) | 17-19 F "normal" | 17-19 F "normal" |
| Twenty-Year Average (1980-1999) (mean +- 1 Std. Dev.) | 16-19 F "normal" | 17-19 F "normal" |

**PRECIPITATION**

| | July | August |
|---|---|---|
| 2000 | 0.8 in | 0.7 in |
| Ten-Year Average (1990-1999) (mean +- 1 Std. Dev.) | 0.6-2.5 in "normal" | 0.7-2.3 in "normal" |
| Twenty-Year Average (1980-1999) (mean +- 1 Std. Dev.) | 0.4-2.7 in "normal" | 0.6-2.1in "normal" |

Source: NOAA climate data for Division 4, Washington

Provisional Data

| Site | Stream Temperature (C) Instantaneous Maximum | Maximum Daily Average | MWAT | MWMT | Estimated Canopy Closure (% ) | Elevation (ft) | Minimum Canopy Target (for 16C) | Conforms to TFW Temperature Screen? |
|---|---|---|---|---|---|---|---|---|
| Gale Creek 1 | 20 | 17 | 16 | 19 | 30 | 1440 | 60 | yes |
| Gale Creek 2 | 19 | 17 | 16 | 18 | 75 | 1130 | 70 | no * |
| S.F. Gale Creek | 16 | 15 | 14 | 15 | 90 | 1450 | 60 | yes |
| W.F. Gale Creek | 16 | 15 | 14 | 15 | 90 | 1160 | 60 | yes |
| Wilkeson Creek 1 | 16 | 15 | 14 | 15 | 60 | 1320 | 60 | yes |
| Wilkeson Creek 2 | 15 | 14 | 13 | 14 | 80 | 1320 | 60 | yes |
| Wilkeson Creek 3 | 17 | 16 | 15 | 16 | 75 | 1130 | 70 | no * |
| Wilkeson Creek 4 | 18 | 16 | 15 | 17 | 55 | 810 | 70 | yes |
| South Prairie Creek 1 | 12 | 12 | 11 | 12 | 90 | 1880 | 50 | yes |
| South Prairie Creek 2 | 13 | 13 | 12 | 12 | 90 | 1880 | 50 | yes |
| South Prairie Creek 3 | 15 | 13 | 13 | 14 | 55 | 1630 | 60 | no ** |
| E. F. South Prairie Cr. | 14 | 12 | 11 | 13 | 55 | 1640 | 50 | yes |

* observed temperature higher than elevation/canopy combination would suggest
**observed temperature lower than elevation/canopy combination would suggest

Plum Creek
16 November 2000

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Existing water temperature conditions in the South Prairie Creek watershed reflect seasonal variation. Cooler temperatures occur in the winter, while warmer temperatures are observed in the summer. Highest temperatures typically occur in July and August, which is the critical period for temperature TMDL development.

# Technical Analyses

Technical analyses are based on recent field data collection and temperature modeling. The Quality Assurance Project Plans (Roberts, 2000 and 2001) describe the data collection program and methods.

## Data Used in Analysis

**Water Temperature, Air Temperature, and Relative Humidity**

Water temperature, air temperature, and relative humidity were monitored continuously during the summer months in 2001, and partial records are available for 2000. Ten temperature monitoring stations were established over the 10.4-mi (16.8-km) study reaches. Appendix A includes the monitoring data. Data were compiled and analyzed using Microsoft Excel®.

**Discharge Data, Hydraulic Geometry, and Channel Characteristics**

Historical discharge data from the USGS station on South Prairie Creek at the town of South Prairie were used for statistical analyses. Only data from October 1, 1987 through December 31, 2001 were used in the present study, although the gage data include the period 1950 to 1979.

Ecology supplemented the continuous discharge records with instantaneous flows at eight locations between July 2000 and December 2001. Geometry and velocity data were used to generate relationships between discharge (Q) and channel width (w), average channel depth (d), and average velocity (u) using hydraulic geometry coefficients. Width, depth, and velocity can be related to discharge (Q) by power functions:

$$w = a\,Q^{b}$$
$$d = c\,Q^{f}$$
$$u = k\,Q^{m}$$

By continuity of mass,

$$Q = w\,d\,u = a\,Q^{b} * c\,Q^{f} * k\,Q^{m}$$

and

$$a * c * k = 1$$
$$b + f + m = 1$$

Coefficients were determined for individual stations by fitting power curves to data collected for instantaneous discharge measurements. The curves are used to estimate width and depth for flow regimes not specifically measured. Table 8 summarizes these equations. Relationships for a particular station were assumed to hold for reaches half the distance to the upstream station and half the distance to the downstream discharge station.

Table 8. Hydraulic geometry relationships for South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch (discharge, Q, in $m^3/s$)

| ***Station*** | ***Width (m)*** | ***Depth (m)*** | ***Velocity (m/s)*** |
|---|---|---|---|
| SPCLB | $W = 17.571\ Q^{0.0976}$ | $D = 0.177\ Q^{0.3597}$ | $U = 0.3215\ Q^{0.5427}$ |
| SPCSP | $W = 15.316\ Q^{0.1101}$ | $D = 0.3401\ Q^{0.2267}$ | $U = 0.192\ Q^{0.6632}$ |
| SPCB4 | $W = 15.443\ Q^{0.1916}$ | $D = 0.3101\ Q^{0.2509}$ | $U = 0.2088\ Q^{0.5574}$ |
| SPCB2 | $W = 11.679\ Q^{0.4347}$ | $D = 0.2474\ Q^{0.1989}$ | $U = 0.346\ Q^{0.3664}$ |
| SPCB1 | $W = 15.96\ Q^{0.0152}$ | $D = 0.3088\ Q^{0.376}$ | $U = 0.2029\ Q^{0.6088}$ |
| SPCM | $W = 18.903\ Q^{0.0798}$ | $D = 0.2095\ Q^{0.4809}$ | $U = 0.2525\ Q^{0.4393}$ |

Additional channel characteristics were provided by habitat surveys, which were conducted in August 2001 at each temperature monitoring location. Ten cross sections were established, beginning at the monitoring station at 100-ft (33-m) intervals. At each cross section, the wetted width, bankfull width, width of near-stream disturbance zone, channel incision, and bankfull depth were recorded.

**Topographic Shade, Aspect, and Gradient**

Shade angles from topographic features were calculated to the east, south, and west based on solar azimuth and a 10-m digital elevation model (DEM). The channel centerlines were used to estimate reach aspect. Channel gradient was averaged for each reach from electronic USGS quadrangle maps.

**Riparian Vegetation and Effective Shade**

Current vegetation characteristics, including height and density, are used to estimate effective shade from the riparian zone. No vegetation data layer was available for the watershed, however. Vegetation polygons were estimated from the most recent orthophotos[5] within 500 ft (150 m) of the centerline of South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch. Vegetation height, type, and canopy cover categories were assigned to each polygon, based on visual interpretation and field observations collected in the habitat surveys described above. Polygon attributes were verified or refined in the field using observations of vegetation type and a laser range finder for vegetation height at all accessible locations.

Habitat surveys also provided densiometer readings at ten cross sections upstream of each temperature monitoring location. Hemispherical photography was used to record canopy cover

[5] South Prairie Creek riparian zone orthophotos were available from 7/20/98 for the upstream model boundary to SPCB2; for the mouth to SPCB2, 7/18/90 was the most recent imagery. For Wilkeson Creek, orthophotos were available from 7/20/98 for the 1.6 mi (2.6 km) upstream of the mouth; for the headwaters to 1.6 mi (2.6 km), data were available from 7/15/90. The 7/20/98 imagery covered nearly the entire Spiketon Creek/Ditch riparian zone, from the mouth to a point 4.9 mi (6.2 km) upstream.

at monitoring stations. Photos were evaluated using HemiView Canopy Analysis Software version 2.1 (Delta-T Devices Ltd., 1999) based on the path of the sun for a date.

## Critical Conditions

Seasonal estimates for stream flow, solar flux, and climatic variables are taken into account to develop critical conditions. During the July 2000 through December 2001 monitoring period, daily water temperature in South Prairie Creek peaked on August 1, 2000 and August 10, 2001, with highest 7-day average of daily maximum temperatures occurring July 29 through August 4, 2000 and August 9 through August 15, 2001 for each summer. Thus, the critical period for temperature monitoring occurs in late July to early August, and the 7-day averages were used in the analysis.

Critical stream flows for the temperature TMDL were evaluated as the lowest 7-day average flows with a 2-year recurrence interval (7Q2) and 10-year recurrence interval (7Q10) for the months of July and August. The 7Q2 stream flow represents conditions that occur during a typical climatic year, and the 7Q10 stream flow represents a reasonable worst-case climatic year at the South Prairie USGS gage. WQHYDRO (Aroner, 1994) was used to calculate 7Q2 and 7Q10 using a variety of distributions, as shown in Table 9. Flows selected to represent the critical conditions are 40 cfs (1.1 cms) for 7Q2 and 28 cfs (0.79 cms) for 7Q10.

Table 9. Flow statistics for USGS gage (12095000) on South Prairie Creek.

| ***Statistic*** | ***Distribution*** | ***Discharge*** | ***95% C.I.*** |
|---|---|---|---|
| 7Q2 | Distribution free | 39 cfs<br>1.1 cms | |
| | Log Pearson III<br>(no bias correction) | 40 cfs<br>1.1 cms | 33 to 49 cfs<br>0.92 to 1.4 cms |
| | Weibull | 41 cfs<br>1.2 cms | 30 to 52 cfs<br>0.84 to 1.5 cms |
| | Log-Normal<br>(3 parameter) | 39 cfs<br>1.1 cms | 33 to 48 cfs<br>0.94 to 1.4 cms |
| 7Q10 | Distribution free | 29 cfs<br>0.82 cms | |
| | Log Pearson III<br>(no bias correction) | 28 cfs<br>0.80 cms | 20 to 35 cfs<br>0.57 to 0.98 cms |
| | Weibull | 27 cfs<br>0.75 cms | 18 to 35 cfs<br>0.50 to 1.0 cms |
| | Log-Normal<br>(3 parameter) | 29 cfs<br>0.81 cms | 26 to 32 cfs<br>0.72 to 0.91 cms |

Air temperature is available for the USGS meteorology station at South Prairie since 1999. Because the South Prairie air temperatures are highly correlated with the SeaTac Airport temperatures ($R^2 = 0.92$ for the 7-day average of daily maximum temperatures), the long-term SeaTac Airport record was used to develop statistics from the period 1948 to 2001. The annual maximum values of the 7-day running average of daily maximum temperatures were ranked.

The median (50th percentile) was used for typical hydrologic conditions, while the daily maximum temperature exceeded 10% of the time (90th percentile) was used for extreme hydrologic conditions. Table 10 summarizes the values from the SeaTac record and estimated for the South Prairie station.

Table 10. Air temperature statistics for South Prairie Creek.

| | Typical Hydrologic Condition (exceeded 50% of time) | | Extreme Hydrologic Condition (exceeded 10% of time) | |
|---|---|---|---|---|
| | (°C) | (°F) | (°C) | (°F) |
| SeaTac Airport (National Weather Service) | 28.7 | 83.7 | 30.5 | 86.9 |
| South Prairie Creek from regression with SeaTac record | 28.6 | 83.5 | 30.4 | 86.7 |

## Analytical Framework for Linking Shade and Instream Temperature

Riparian vegetation, stream morphology, hydrology, climate, and geographic location influence stream temperature. Stream temperature represents the concentration of heat. If heat loads gained by a stream reach exceed losses, the temperature increases. The change in heat is generally small compared with the heat entering from upstream. The heat budget expresses this in mathematical form:

$$J_{net} = J_{longwave} + J_{solar} + J_{convection} + J_{evaporation} + J_{bed} + J_{hyporheic} + J_{in} + J_{out}$$

where J represents the flux of each component, which can be positive or negative. Objects emit absorbed heat in the form of long-wave radiation ($J_{longwave}$). The atmosphere provides some long-wave radiation to water bodies, but more tends to be emitted by the water bodies, generally resulting in a net loss of heat. Solar, or short-wave radiation, ($J_{solar}$) tends to dominate the heat budget where effective shade is low. Solar radiation inputs peak at mid-day and do not occur at night. Heat can be transferred through convection ($J_{convection}$). If a stream is hotter than the air temperature above it, heat is transferred from the stream to the air, resulting in a decreased water temperature. Wind transfers that heat horizontally and dissipates air temperature gains next to the stream surface, which maintains the gradient of temperature that drives convection losses from the stream. If air temperature exceeds water temperature, heat is transferred into the stream. However, this term tends to be small relative to other heat fluxes. Evaporation ($J_{evaporation}$) results in a transfer of latent heat from the water body to the air (Dingman, 1994), although it is small relative to other terms in the heat budget equation. Finally, heat can be transferred to or from the bed through advective exchange of water containing heat ($J_{hyporheic}$) or by conduction ($J_{bed}$) with the sediments (Beschta et al., 1987). In addition, heat is advected in ($J_{in}$) and out ($J_{out}$) of a reach via surface water transport. Figure 10 provides an example of the heat flux components for a reach downstream of the town of South Prairie under 7Q10 hydrologic conditions.

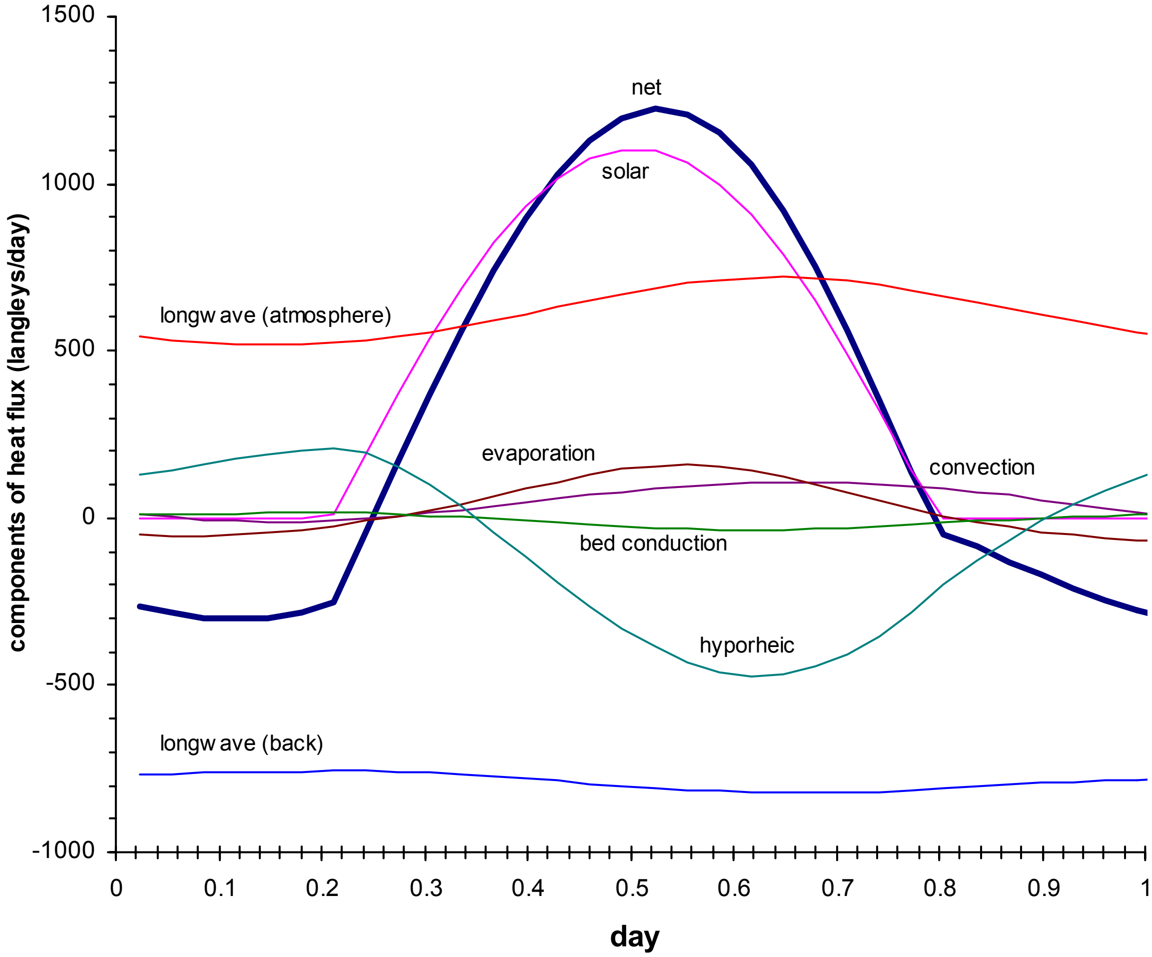



Figure 10. Heat flux components for South Prairie Creek downstream of South Prairie for 7Q10 conditions.

While climate and geographic location are outside of direct human control, riparian condition, channel morphology, and hydrology are affected by land use activities. Specifically, the elevated summer stream temperatures attributed to anthropogenic sources in the South Prairie Creek basin result from the following:

- Riparian vegetation disturbance reduces stream surface shading by decreasing riparian vegetation height, width, and density, thereby increasing the amount of solar radiation reaching the stream surface. Timber harvest, residential development, and agricultural activities decrease shade.
- Point source discharges from two wastewater treatment plants contribute heat loads to receiving water bodies.
- Channel widening (increased width to depth ratios) increases the stream surface area exposed to solar radiation.

- Reduced summer base flows may result from instream withdrawals and hydraulically connected groundwater withdrawals or hydrologic effects of timber harvesting. Reducing the amount of water in a stream can increase stream temperature (Brown, 1972).
- Reduced surface water/groundwater interaction, also called hyporheic exchange flow, increases surface water temperatures by reducing heat loss to gravels and cool groundwater discharges. This can result from decreased channel complexity and/or clogging of the gravels by fine material.

The present study includes the effects of reduced shade, point source heat discharges, channel widening, typical and extreme baseflow conditions, and the effect of hyporheic exchange flow. The analysis includes flow as a fixed variable only, since flows do not fall under the jurisdiction of the TMDL program. However, any activities that increase water withdrawals or decrease groundwater discharge or hyporheic exchange flow will exacerbate the temperature exceedances on South Prairie Creek and its tributaries. Similarly, channel widening will increase the channel surface area exposed to solar radiation and increase the surface water temperature of South Prairie Creek and its tributaries.

**Effective Shade Definition**

Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Effective shade is a function of several landscape and stream geometric relationships. Some of the factors that influence effective shade include the following:

- latitude and longitude
- time of year
- stream aspect and width
- vegetation buffer height, width, overhang, and canopy density
- topographic shade angles

In the Northern Hemisphere, the earth tilts on its axis toward the sun during the summer months allowing increased day length and higher solar altitude, both of which are functions of solar declination[6]. Geographic position (e.g., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream orientation. Riparian vegetation height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation, which results in shade. The solar position has a vertical component (altitude) and a horizontal component (azimuth) that are both functions of time/date (solar declination) and the earth's rotation (hour angle). Relatively simple geometry describes the relationships using methods developed by the solar energy industry.

Percent effective shade is the most straightforward stream parameter to monitor and calculate, and it is easily translated into quantifiable water quality management and restoration objectives. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The measured solar load at the stream surface can be measured with hemispherical photography or estimated using mathematical shade simulation computer programs.

[6] measure of the earth's tilt toward the sun

**Development of Effective Shade for South Prairie Creek and its Tributaries**

The TTOOLS extension for ArcView, developed by ODEQ (2001) and modified by Ecology, samples and processes GIS data needed to calculate effective shade. First, South Prairie Creek and its tributaries were broken into 100-ft (30.5-m) segments. At the upstream end of each segment, TTOOLS develops the following attributes: stream aspect, elevation, gradient, topographic shade angle to the east, south, and west, channel width, distance from each channel bank to the edge of the nearstream disturbance zone (NSDZ), and the riparian vegetation code at varying distances from the edge of the NSDZ. The NSDZ is the active stream channel area without riparian vegetation, and includes features such as gravel bars.

Riparian vegetation is sampled at nine locations to either side of the channel (Figure 11). The sampling interval is every 15 ft (4.6 m) for a total of 135 ft (41 m) to each side of the NSDZ. Attributes for each riparian code include a unique combination of vegetation type, height, density and overhang. Overhang is generally assumed to be 10% of the vegetation height in the absence of other information. Table 11 lists the riparian vegetation codes used for the South Prairie Creek study. Appendix B presents an example of the vegetation datalayer developed for South Prairie Creek, with the current distribution of vegetation types within a 500-ft (150-m) buffer of the stream centerline.

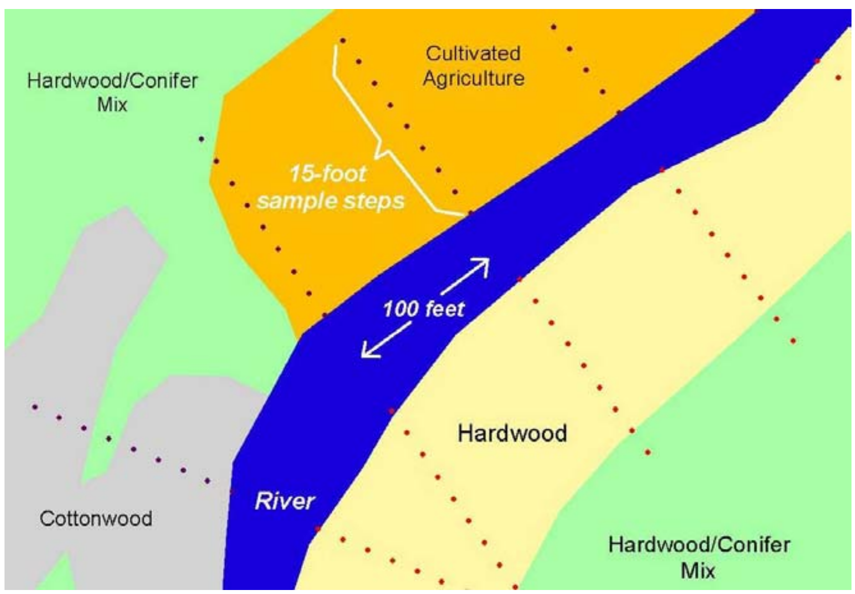



Figure 11. Vegetation sampling example.

Table 11. Riparian vegetation codes and characteristics used for South Prairie Creek.

| Code | Description | Height | | Density | Overhang | |
|---|---|---|---|---|---|---|
| | | (ft) | (m) | (%) | (ft) | (m) |
| 302 | Pasture, field, lawn | 2 | 0.5 | 75% | 0 | 0.0 |
| 400 | Road, barren land | 0 | 0.0 | 0% | 0 | 0.0 |
| 500 | Mixed forest | 120 | 36.6 | 90% | 8 | 2.4 |
| 502 | Mixed forest | 150 | 45.7 | 95% | 15 | 4.6 |
| 550 | Mixed forest | 80 | 24.4 | 25% | 8 | 2.4 |
| 551 | Mixed forest | 40 | 12.2 | 25% | 4 | 1.2 |
| 600 | Hardwood forest | 90 | 27.4 | 90% | 9 | 2.7 |
| 601 | Hardwood forest | 60 | 18.3 | 90% | 4 | 1.2 |
| 700 | Conifer forest | 100 | 30.5 | 95% | 10 | 3.1 |
| 800 | Shrubs | 15 | 4.6 | 75% | 2 | 0.5 |
| 3011 | Floodplain, river bottom | 0 | 0.0 | 0% | 0 | 0.0 |

The effective shade algorithm, modified from Boyd (1996) using the methods of Chen et al. (1998a and 1998b), uses the riparian vegetation codes in each zone, stream aspect, and topographic shade angles, together with a selected date and latitude/longitude to estimate effective shade for each of the 100-ft (30.5-m) segments. Results are averaged for ten segments to create shade characteristics for 1000-ft (305-m) reaches, which are used by the computer model QUAL2K, discussed below.

Figure 12 presents effective shade predicted along South Prairie Creek from SPCSR downstream to SPCM. Effective shade ranges from 45 to 70% due to a combination of vegetation removal, a wide NSDZ, and relatively little topographic shade from SPCSR to just upstream of SPCLB. South Prairie Creek flows through a narrow canyon with mature vegetation interrupted with some vegetation removal from SPCLB to just downstream of the Wilkeson Creek confluence (SPCWC). From the town of South Prairie downstream, residential and agricultural land use practices have removed or reduced riparian vegetation to a narrow buffer.

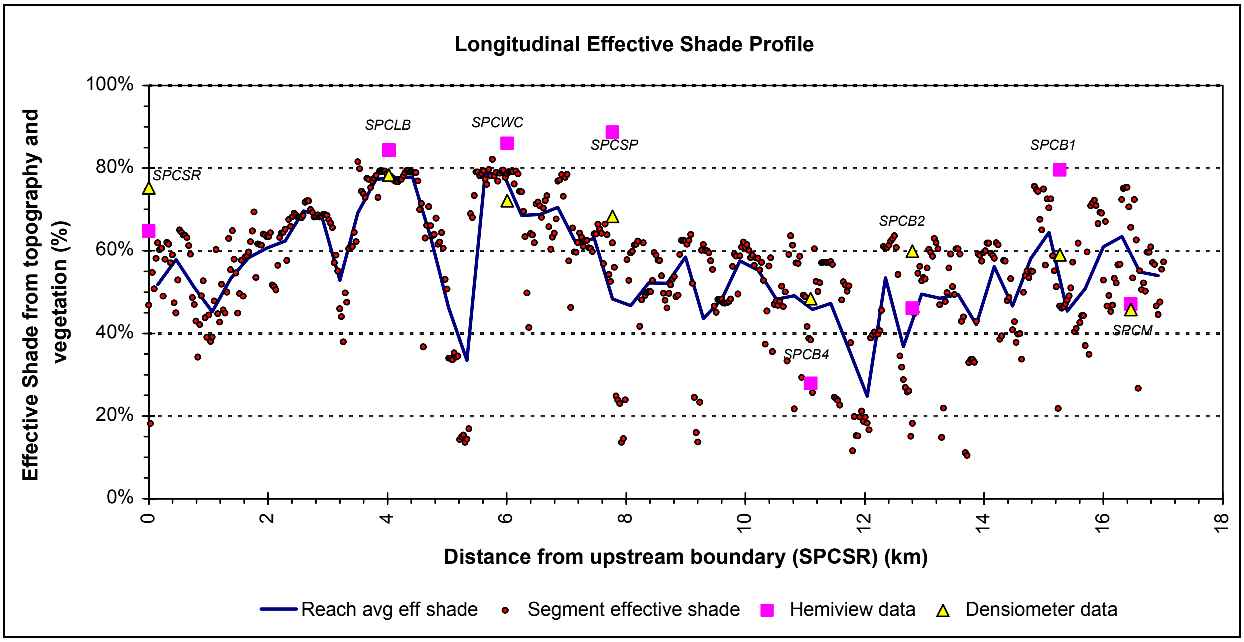



Figure 12. Longitudinal profile of effective shade for South Prairie Creek estimated using Shadealator.

HemiView results and densiometer readings from August 2001 generally support the predicted trends in effective shade from Shadealator. The high HemiView shade calculated at SPCSP and SPCB1 are likely due to interference from bridge structures.

# Model Approach

## QUAL2K Temperature Model Development

The QUAL2K model (Chapra, 2001) was used to calculate the components of the heat budget and to simulate water temperatures. QUAL2K, a Visual Basic application in a Microsoft Excel® environment, uses the kinetic formulations for the surface water heat budget described above and presented in Chapra (1997). In summary, QUAL2K is a steady-state, one-dimensional model that simulates diurnally varying water temperature using a finite-difference numerical method. Therefore, a single flow condition is selected to represent a given condition, such as a 7-day average flow. For temperature simulation, solar radiation, air temperature, relative humidity, headwater temperature, and point source/tributary water temperatures are specified as diurnally varying functions with a minimum and maximum value and time of the maximum value.

Heat flux components were calculated along the main stem of South Prairie Creek, with Wilkeson Creek, Spiketon Creek/Ditch, and the South Prairie wastewater treatment plant included as point sources. The model was calibrated using data collected during the hottest conditions of 2001 (August 9 through August 15) and verified with two different data sets:

hottest water temperatures of 2000 (July 29 through August 4) and coolest steady-state maximum temperatures of 2001[7] (August 1 through August 7).

Table 12 summarizes model input data specified for any model run. Following are descriptions of how specific input parameters were developed:

- Differential flows along South Prairie Creek were calculated for calibration and validation runs using field measurements. Flows were estimated for ungaged locations using the ratio of watershed areas with a measured flow location. For 7Q2 and 7Q10 analyses, the distribution of flows throughout the watershed was based on regression equations between the USGS gage at South Prairie and instantaneous flow measurements recorded during the present study. Differential inflows are specified as total inflow rate over a specified distance.
- Headwater temperature boundary conditions were established using monitoring data for the calibration and validation data sets from station SPCSR.
- Reach hydraulic geometry coefficients were established for monitoring stations and were assumed to hold over half the distance to stations upstream and downstream. The hydraulic geometry used in calibration and validation runs was also used for 7Q2 and 7Q10 runs. Calibration flows (36 cfs or 1.0 cms at SPCSP) were close to 7Q2 conditions (40 cfs or 1.1 cms).
- Sediment thermal properties were based on literature values for wet sand with a porosity of 0.7.
- Hyporheic exchange flow was a calibration parameter held constant for the validation, 7Q2, and 7Q10 runs.
- Air temperatures for the calibration run were based on monitoring data. Minimum daily air temperatures increased slightly downstream from 10.9 to 11.9°C at the mouth with a peak of 12.3°C at SPCSP, but maximum daily air temperatures increased significantly from 23.9 to 29.0°C at the mouth with SPCB2 exhibiting a peak of 30.5°C. The variation is equivalent to a lapse rate of 50°C/km, which is far greater than that explained by the adiabatic lapse rate of 6.5°C/km under dry conditions. The distribution for the calibration period was used to relate temperature at each site to the SPCSP riparian air temperature measured in the 2001 data collection program. Station SPCSP is closest to the USGS meteorology gage. Tidbit data were correlated with the USGS meteorological station data ($R^2 = 0.92$) but were slightly cooler, likely due to the riparian microclimate. The 2000 validation period uses USGS meteorological station data to generate the SPCSP riparian temperatures and the longitudinal air temperature profile. The USGS meteorological data were related to the SeaTac Airport record. Thus, the longitudinal air temperature profiles were developed for 7Q2 and 7Q10 conditions based on the SeaTac air temperature data, corrected for South Prairie conditions.
- Relative humidity values for the calibration and validation runs were based on 2001 data for the mouth of Wilkeson Creek (WCM) to characterize reaches from the upstream boundary (SPCSR) to the town of South Prairie (SPCSP) and 2001 data from the mouth of South

[7] The coolest 7-day average of maximum daily temperatures occurred August 22-28, 2001. However, these temperatures occurred during a storm, and unsteady conditions cannot be modeled using QUAL2K. Therefore, the coolest peak temperatures during steady-state conditions were used for the second validation data set.

Prairie Creek (SPCM) for the remainder of the study area. Minimum relative humidity occurs in late afternoon, while nearly 100% relative humidity occurs just before sunrise, even in summer conditions. The 2000 validation, 7Q2, and 7Q10 runs use 2001 monitoring results of approximately 60% minimum relative humidity and 100% maximum relative humidity.

- Wind speed was recorded near the South Prairie wastewater treatment plant in summer 2001, and data from the calibration and validation time periods were used. The 2000 validation uses the SeaTac data. The calibration values were used for 7Q2 and 7Q10 runs. Pollution index was set to 2 (clear) for all runs.
- Tributary point source inputs were developed from monitoring data at the mouth of Wilkeson Creek (WCM) and the mouth of Spiketon Creek/Ditch (SKT165/SKTM) for the 2001 calibration and validation and 2000 validation runs. For 7Q2 and 7Q10 conditions, maximum temperatures were assumed to be 18°C, with minimum temperatures set to the calibration run values.
- The South Prairie wastewater treatment plant point source inputs were developed from monitoring data reported in the Daily Monitoring Reports submitted to Ecology by the plant operator. Only one daily temperature is reported; 7-day average values of this temperature were used for both the maximum and minimum effluent temperature, essentially holding the temperature constant throughout the day.
- Diffuse source temperatures were assigned the average annual temperature (10.9°C), based on SeaTac mean daily air temperatures for the period October 1999 through September 2001[8]. The shape of the watershed is such that only very small surface tributaries other than Wilkeson Creek, Spiketon Creek/Ditch, and the unnamed tributary from the town of South Prairie enter the main stem of South Prairie Creek. Therefore, differential flows are assumed to be dominated by groundwater, and groundwater temperatures are often similar to the mean annual air temperature (Theurer et al., 1984).

Table 12. QUAL2K model input data summary

| ***Category*** | ***Model Input Data*** |
|---|---|
| Run Information | Date, sunrise |
| Headwater | Latitude, longitude, elevation, discharge, discharge coefficients of upstream reach, minimum temperature, maximum temperature, time of maximum temperature |
| Reach | Reach labels, length, latitude, longitude, hydraulic geometry coefficients, effective shade, sediment thermal properties, hyporheic exchange flow |
| Meteorology | Minimum air temperature, maximum air temperature, time of maximum air temperature, minimum relative humidity, maximum relative humidity, time of maximum relative humidity, wind speed, cloud cover, pollution index (all specified by reach) |
| Point Sources | Name, location of inflow point, discharge, maximum temperature, minimum temperature, time of maximum temperature |
| Diffuse Sources | Upstream extent of source, downstream extent of source, discharge, temperature |

[8] The long-term (1948 to 2001) mean daily air temperature is similar at 10.7°C.

## Model Calibration

Figure 13 presents the calibration run for South Prairie Creek for the 7-day average conditions for the period August 9 through August 15, 2001. The model appropriately represents the maximum temperature profile for the calibration conditions. The uncertainty of the temperatures predicted by the QUAL2K model can be assessed using the root mean square error[9] (RMSE) of the predicted versus observed maximum and minimum temperatures. For the calibration period, the RMSE is 0.54°C.

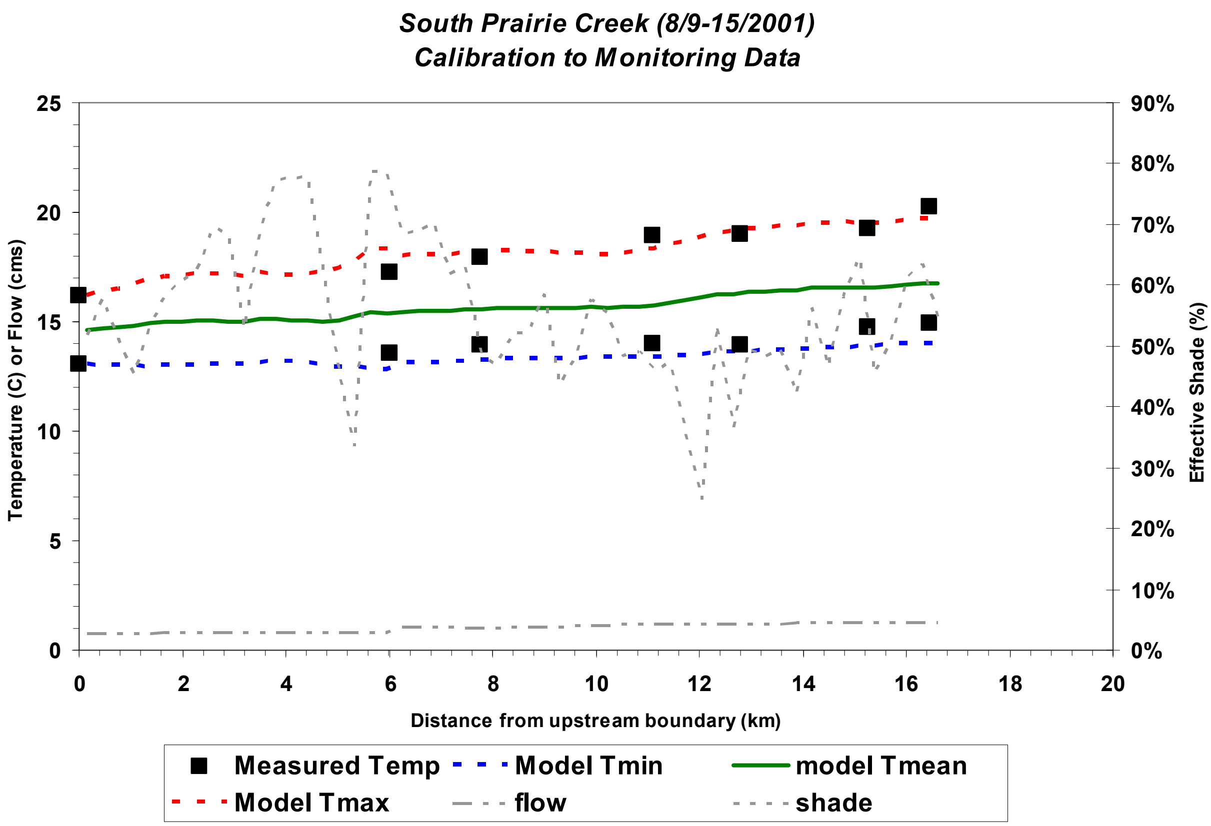



Figure 13. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the calibration period August 9 through 15, 2001 (RMSE = 0.54°C)

## Model Validation

Two additional data sets were evaluated to verify that the model appropriately represents the temperature processes important to South Prairie Creek. Figure 14 compares the temperatures predicted by the QUAL2K model with measured data for the warm validation period, July 29 through August 4, 2000, using the effective shade and hyporheic exchange flows calibrated for the 2001 calibration period. Model uncertainty is relatively low, with a RMSE of 0.64°C.

[9] RMSE is the square root of the sum of the squared differences between observed and predicted values.

Similarly, Figure 15 compares predicted temperatures with measured data for the cool validation period, August 1 through August 7, 2001, using the calibration values for effective shade and hyporheic exchange flows. The RMSE is slightly higher at 0.91°C, but the model still appropriately represents cool peak temperature conditions.

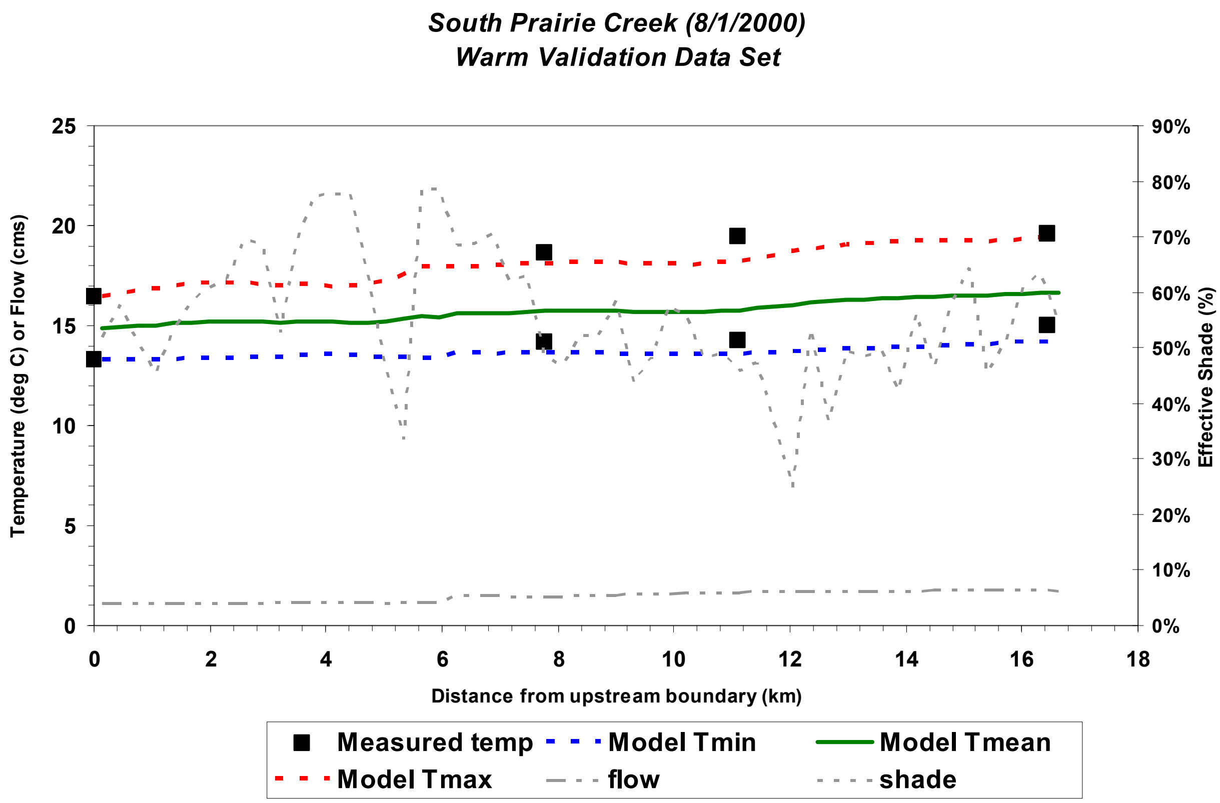



Figure 14. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the warm validation period of July 29 through August 4, 2000 (RMSE = 0.64°C).

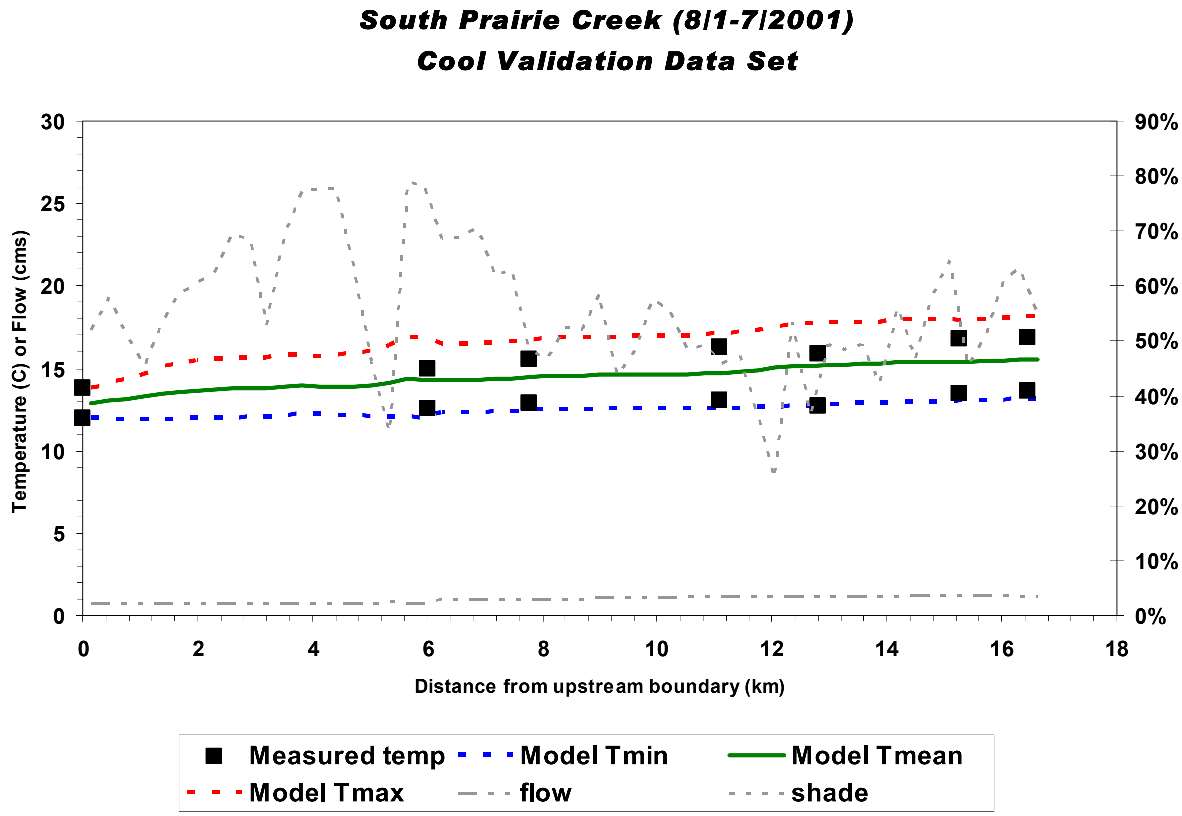



Figure 15. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the cool validation period of August 1 through 7, 2001 (RMSE = 0.91°C).

### 7Q2 and 7Q10 Conditions

Predicted daily maximum temperatures for typical and extreme hydrologic conditions are presented in Figure 16 with the calibration results. Because calibration air temperature and flow conditions were close to 7Q2 conditions, the predicted temperatures are similar. However, the higher air temperatures and lower flow conditions expected under 7Q10 conditions result in significantly increased water temperatures along the entire length of South Prairie Creek. Lengths of stream exceeding the 18°C standard are 6.9 and 9.2 mi (11.1 and 14.8 km) for typical and extreme hydrologic conditions, respectively.

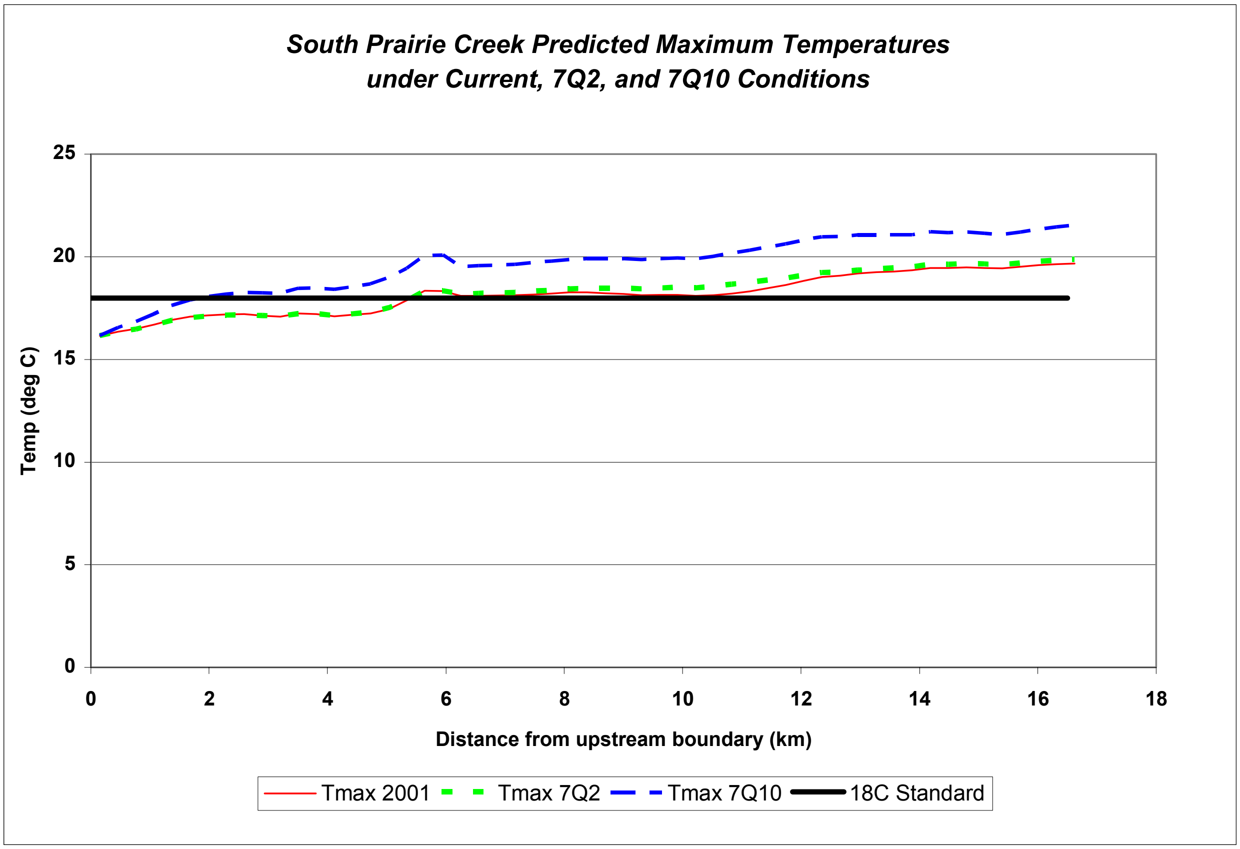



Figure 16. Predicted temperatures in South Prairie Creek under current, typical (7Q2), and extreme (7Q10) hydrologic conditions.

## Loading Capacity

The calibrated QUAL2K model was used to determine the loading capacity for effective shade for South Prairie Creek from the upstream boundary at Spiketon Road (SPCSR) to the mouth. Loading capacity was determined based on prediction of water temperatures under typical and extreme flow and climate conditions combined with a range of effective shade conditions. The 7Q2 low flow was selected to represent a typical climatic year, and the 7Q10 low flow was selected to represent a reasonable worst-case condition for the July-August summer period.

The site potential vegetation is a cedar/hemlock/Douglas fir forest. A tree height of 55 m (180 ft) and canopy density of 90%, based on the current vegetation found along South Prairie Creek at the Wilkeson Creek confluence (SPCWC) and at the Lower Burnett Road crossing (SPCLB) (see Figure 12), was used to define maximum potential effective shade from mature riparian vegetation. The DNR soils datalayer indicates the area has a site index of 129, which represents the height in feet of the dominant or co-dominant vegetation at a stand age of 50 years for forests west of the Cascades. This is close to the highest site index value for all of WRIA 10 (132 ft, or 40 m). Much of the South Prairie Creek riparian area had been modified prior to the 1936 vegetation survey (USFS, 1996), which indicates older trees near the confluence with Wilkeson

Creek (Figure 17). Thus, the current vegetation does not represent undisturbed conditions. The parameters representing mature riparian conditions exceed the height expected within 50 years, based on the site index from soil surveys, and are within the values for mature western Washington forests documented in Beschta et al. (1987).

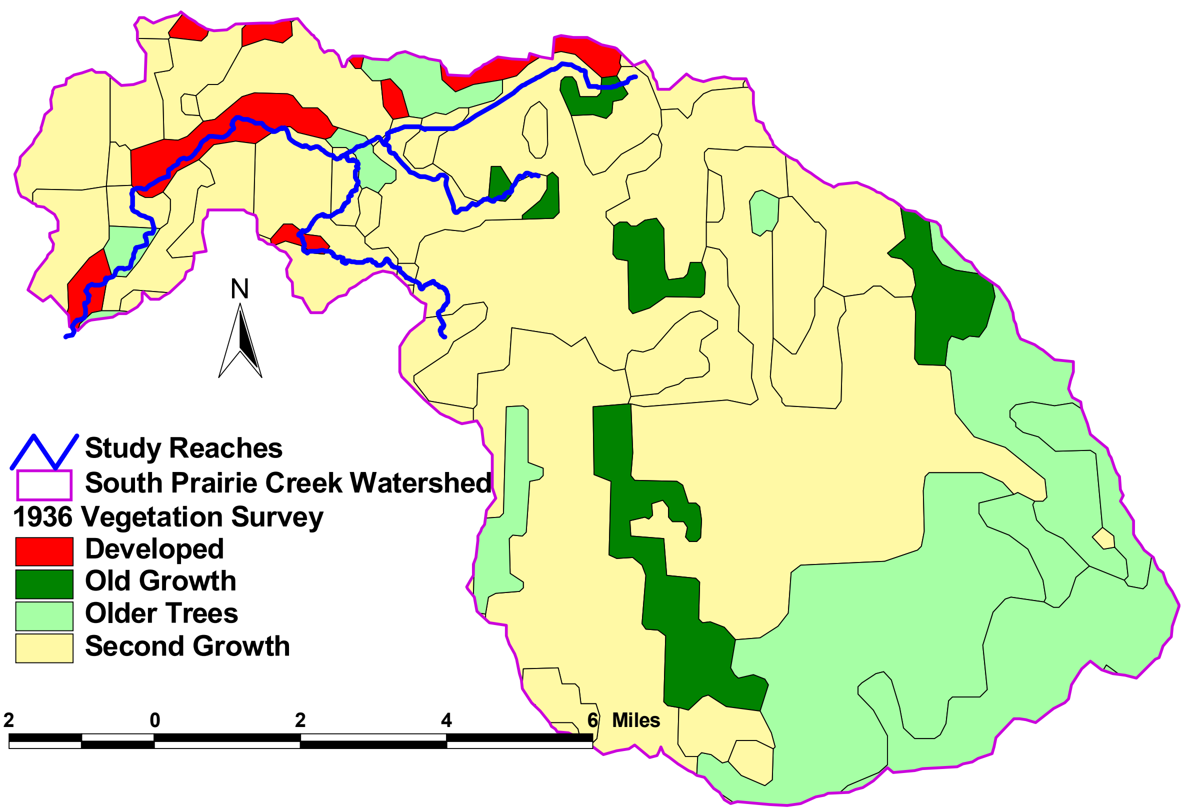
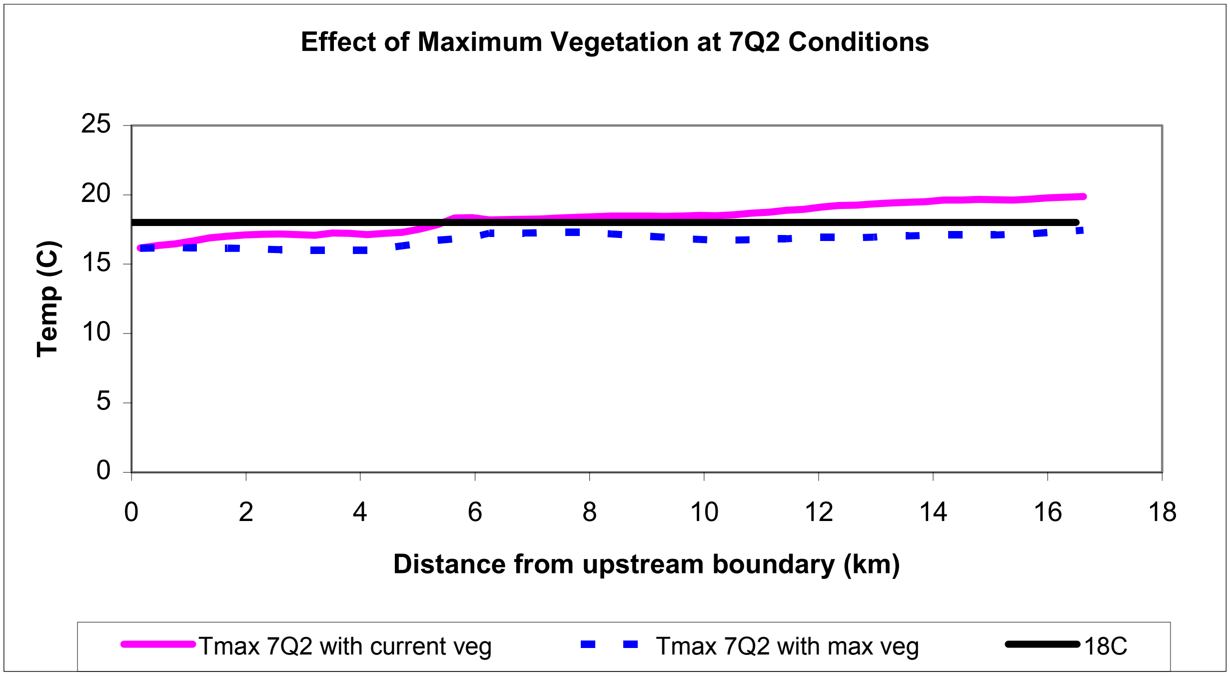



Figure 17. Vegetation present during 1936 vegetation survey.

Figure 18 presents the predicted water temperature in South Prairie Creek for the lowest 7-day average discharge during July and August with a two-year recurrence interval (7Q2) and a ten-year recurrence interval (7Q10). The increase in effective shade from mature riparian vegetation has the potential to significantly decrease water temperature under both typical and extreme hydrologic conditions.



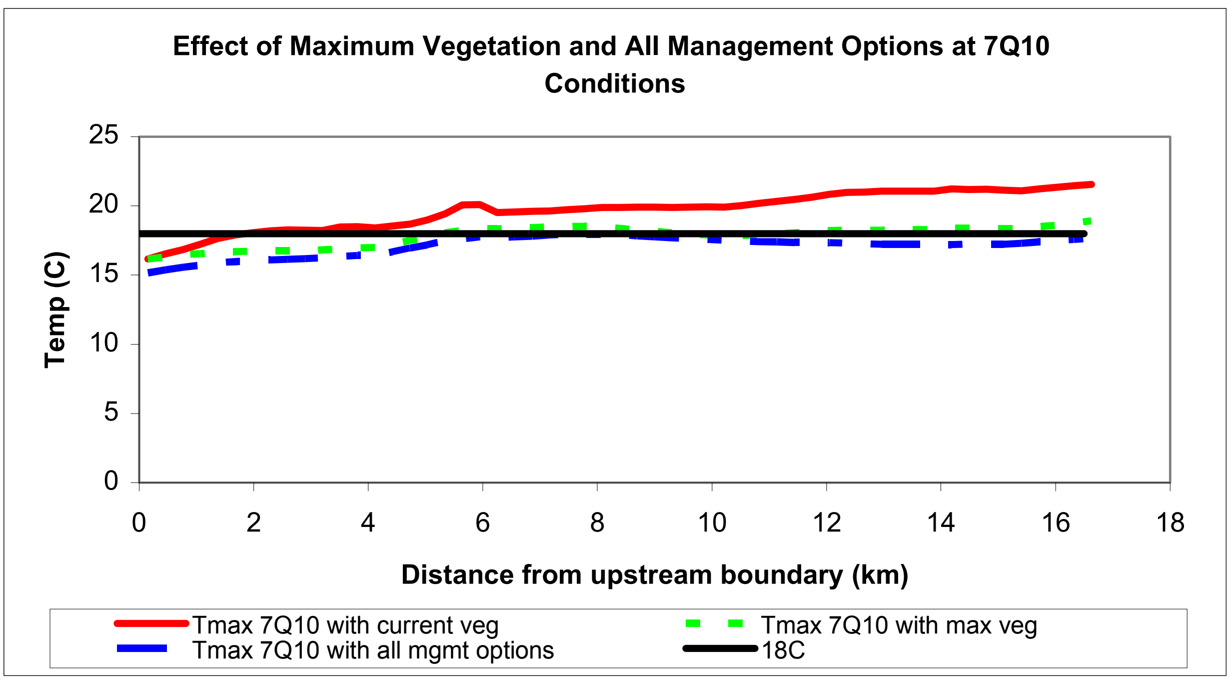




Figure 18. Predicted daily maximum temperature in South Prairie Creek under critical conditions for the TMDL.

With current vegetation, South Prairie Creek exceeds the standard in the lower 11.1 km during 7Q2 conditions. Under mature vegetation conditions within the modeled area, South Prairie Creek should meet standards along the entire length. Under 7Q10 conditions, current vegetation produces water temperatures that exceed 18°C for the lower 14.8 km of the creek with a peak temperature of 21.5°C. For the same flow conditions with mature vegetation within the model area, solar radiation is significantly attenuated such that an additional 7.8 km meets the 18°C criterion and temperatures peak at 18.9°C.

The background temperature expected within the study area was determined using the upstream boundary condition measured in 2001. The area was simulated with no upstream water withdrawals, mature riparian vegetation throughout the model area, and an intact riparian microclimate that reduces air temperatures. Temperature peaks at 18.2°C, as shown in Figure 18. Therefore, 18.2°C represents the background temperature against which anthropogenic impacts and management strategies are compared. Human activities cannot increase the temperature by >0.3°C above this, or 18.5°C.

Maximum vegetation alone will significantly decrease daily maximum temperatures, but South Prairie Creek may exceed 18°C under extreme hydrologic events, represented by 7Q10 conditions. Several additional ongoing and potential management strategies were simulated as a series of scenarios: increased baseflow, decreased upstream boundary condition temperatures, decreased channel widths, and decreased air temperatures. Table 13 summarizes the results.

Table 13. Management scenarios and decreases in peak temperatures in South Prairie Creek for extreme hydrologic conditions (7Q10). [±0.6 to 0.9 °C for model uncertainty]

| ***Scenario*** | ***$T_{max}$ (°C)*** | ***Δ $T_{max}$**** | ***Length <18°C*** | |
|---|---|---|---|---|
| Current vegetation** | 21.5 | (2.6) | 2.0 km | 12% |
| Mature riparian vegetation | 18.9 | 0.0 | 7.0 km | 42% |
| No DSHS withdrawal (increase headwater discharge by 3.5 cfs = 0.10 $m^3/s$) | 18.8 | 0.1 | 8.2 km | 49% |
| No DSHS withdrawal and augment flows another 6.5 cfs | 18.5 | 0.4 | 13.1 km | 78% |
| No DSHS withdrawal and cool headwater boundary condition $T_{max}$ by 1°C to 15.16°C | 18.7 | 0.2 | 10.7 km | 64% |
| No DSHS withdrawal and cool headwater boundary condition $T_{max}$ by 2°C to 14.16°C | 18.5 | 0.4 | 14.0 km | 84% |
| No DSHS withdrawal and cool Wilkeson Creek $T_{max}$ to 17°C | 18.7 | 0.2 | 9.8 km | 58% |
| No DSHS withdrawal and decrease channel width near mouth by 15% from 19m to 16m | 18.6 | 0.3 | 8.2 km | 49% |
| No DSHS withdrawal and keep SPCSP $T_{air}$ constant downstream to mimic riparian microclimate | 18.3 | 0.6 | 12.5 km | 75% |
| No DSHS withdrawal, $T_{air}$ constant from SPCSP downstream, decrease width, decrease SPC upstream boundary by 1°C, decrease Wilkeson Creek by 1°C | 18.0 | 0.9 | 16.6 | 100% |

* compared with maximum potential vegetation
** current vegetation produces peak temperatures 2.6°C greater than mature riparian vegetation

First, the streamflow at the upstream model boundary was increased under 7Q10 conditions to simulate a retired water right or other flow augmentation. DSHS may no longer exercise its water right of 3.5 cfs (0.10 cms). Adding the equivalent volume to the headwater boundary condition reduces the peak temperature to 18.°C compared with 18.9°C for maximum potential vegetation; 8.2 km or 49% of the model study area would have surface water temperatures less than 18°C. If the upstream boundary discharge increased by another 6.5 cfs, or a total of 10 cfs including the DSHS water right, peak temperatures would decrease further to 18.5°C, and 78% of the study area would not exceed 18°C.

Second, to simulate the results of the TFW Agreement, the daily maximum temperature at the upstream boundary in South Prairie Creek was decreased by 1°C and 2°C to 15.16°C and 14.16°C, respectively. Peak temperatures would decrease from 18.9 in South Prairie Creek to 18.7 in South Prairie Creek and the length of stream not exceeding 18 in South Prairie Creek would increase from 8.2 to 10.7 km. A 2°C increase would result in a decrease in peak temperature from 18.9°C to 18.5°C, and 14.0 km (84%) of the study area would not exceed 18°C. Similarly, the Wilkeson Creek discharge was reduced to 17°C. This results in a similar decrease in peak temperature from 18.9°C to 18.7°C and increase in length of stream not exceeding 18°C from 8.2 to 9.8 km.

Third, by decreasing the channel width near the mouth by 15% from 62 ft to 53 ft (19 m to 16 m), peak temperatures decrease from 18.9°C to 18.6°C; the length of stream not exceeding 18°C would not change.

Finally, the model was used to simulate the effects of potential air temperature decreases due to a riparian microclimate that could result from continuous mature riparian vegetation. As described under Model Approach, longitudinal air temperatures varied from a maximum of 23.9°C during 2001 at the upstream boundary (SPCSR) to 29.0°C at the mouth (SPCM). This increase is far greater than can be explained by the dry adiabatic lapse rate to account for changes of elevation. The 2001 distribution of peak temperatures was used to relate air temperatures at the USGS meteorology station to riparian air temperatures upstream and downstream. The lack of continuous, mature riparian vegetation downstream of the town of South Prairie likely contributed to the 6.1°C increase in air temperatures as compared with the upstream area, where topography and vegetation likely create cool riparian microclimates. If the air temperature at the town of South Prairie is held constant downstream, temperature peaks at 18.3°C compared with 18.8°C, and 75% of the model area does not exceed 18°C.

In summary, increased shade from mature riparian vegetation significantly reduces peak water temperatures and increases the length of stream not exceeding 18°C. The secondary beneficial impacts of the riparian microclimate to air temperatures further reduces peak temperatures and increases the length of stream not exceeding 18°C. Increasing baseflow, decreasing upstream boundary temperatures, and decreasing stream width near the mouth also decrease peak temperatures. If all activities coincide, the model predicts that no part of South Prairie Creek will exceed 18°C. However, common practice (Pelletier, 2002; Brock and Stohr, 2002) in temperature TMDLs is to use model uncertainty (RMSE of 0.64°C and 0.91°C, from validation runs) as part of the margin of safety. While peak temperatures will exceed 18°C minus the uncertainty, or 17.1°C to 17.4°C, for all ongoing and potential management strategies, these practices significantly decrease daily maximum temperatures during critical conditions and increase the length of stream not exceeding 18°C. This attenuation of the diurnal thermal range is beneficial to salmonids and other aquatic species using the creeks for refugia.

## Load Allocations

The Load Allocations for effective shade in the South Prairie Creek watershed are as follows:

- For all perennial streams in the South Prairie Creek watershed, the load allocation for effective shade is the maximum potential effective shade that would occur from mature riparian vegetation.

Load Allocations for effective shade are quantified for the modeled reaches of South Prairie Creek in Table 14 as an example. For all other perennial streams in the watershed, the Load Allocation for effective shade is the maximum potential effective shade that would occur from mature riparian vegetation.

Table 14. Effective shade, solar flux, and load allocations for South Prairie Creek.

| Station | Reach | Distance from upstream boundary to middle of stream reach (km) | Distance from mouth to middle of stream reach (km) | Reach-average effective shade for current conditions (%) | Reach-average solar radiation received at the water surface on August 1 with current vegetation (langley/day) | Reach-average effective shade with mature riparian vegetation (%) | Reach-average solar radiation received at the water surface on August 1 with mature riparian vegetation (langley/day) | Load allocation for effective shade assuming mature riparian vegetation (180 ft and 90% canopy density) |
|---|---|---|---|---|---|---|---|---|
| SPCSR | 1 | 0.15 | 16.6 | 52% | 316 | 71% | 193 | 71% |
| | 2 | 0.46 | 16.3 | 58% | 279 | 72% | 191 | 72% |
| | 3 | 0.76 | 16.0 | 51% | 318 | 74% | 186 | 74% |
| | 4 | 1.07 | 15.7 | 45% | 353 | 72% | 167 | 72% |
| | 5 | 1.37 | 15.4 | 53% | 304 | 77% | 185 | 77% |
| | 6 | 1.68 | 15.1 | 58% | 274 | 76% | 153 | 76% |
| | 7 | 1.98 | 14.8 | 61% | 260 | 77% | 156 | 77% |
| | 8 | 2.29 | 14.5 | 62% | 248 | 78% | 152 | 78% |
| | 9 | 2.59 | 14.2 | 70% | 202 | 78% | 146 | 78% |
| | 10 | 2.90 | 13.9 | 68% | 211 | 73% | 149 | 73% |
| | 11 | 3.20 | 13.6 | 53% | 310 | 75% | 177 | 75% |
| | 12 | 3.51 | 13.3 | 69% | 203 | 77% | 165 | 77% |
| SPCLB | 13 | 3.81 | 13.0 | 77% | 147 | 78% | 147 | 78% |
| | 14 | 4.12 | 12.7 | 78% | 148 | 78% | 148 | 78% |
| | 15 | 4.42 | 12.4 | 78% | 148 | 71% | 148 | 78% |
| | 16 | 4.73 | 12.0 | 63% | 242 | 74% | 193 | 74% |
| SKTM | 17 | 5.03 | 11.7 | 46% | 346 | 66% | 167 | 66% |
| | 18 | 5.34 | 11.4 | 33% | 433 | 79% | 223 | 79% |
| | 19 | 5.64 | 11.1 | 79% | 139 | 79% | 139 | 79% |
| SPCWC | 20 | 5.95 | 10.8 | 79% | 141 | 69% | 141 | 79% |
| | 21 | 6.25 | 10.5 | 69% | 206 | 76% | 220 | 76% |
| | 22 | 6.56 | 10.2 | 69% | 202 | 75% | 156 | 75% |
| | 23 | 6.86 | 9.9 | 70% | 187 | 74% | 161 | 74% |
| | 24 | 7.17 | 9.6 | 62% | 252 | 77% | 174 | 77% |
| SPCSP | 25 | 7.47 | 9.3 | 63% | 244 | 78% | 150 | 78% |
| | 26 | 7.78 | 9.0 | 48% | 336 | 76% | 145 | 76% |
| | 27 | 8.08 | 8.7 | 47% | 349 | 78% | 160 | 78% |
| | 28 | 8.39 | 8.4 | 52% | 313 | 78% | 146 | 78% |
| SPCOF | 29 | 8.69 | 8.1 | 52% | 312 | 76% | 147 | 76% |
| | 30 | 9.00 | 7.8 | 58% | 274 | 78% | 155 | 78% |
| | 31 | 9.30 | 7.5 | 44% | 369 | 76% | 149 | 76% |
| | 32 | 9.61 | 7.2 | 48% | 336 | 77% | 154 | 77% |
| | 33 | 9.91 | 6.9 | 58% | 279 | 75% | 154 | 75% |
| | 34 | 10.22 | 6.6 | 55% | 293 | 76% | 162 | 76% |
| | 35 | 10.52 | 6.3 | 48% | 335 | 75% | 158 | 75% |
| SPCB4 | 36 | 10.83 | 5.9 | 49% | 334 | 71% | 167 | 71% |
| | 37 | 11.13 | 5.6 | 46% | 354 | 76% | 190 | 76% |
| | 38 | 11.44 | 5.3 | 47% | 345 | 72% | 160 | 72% |
| | 39 | 11.74 | 5.0 | 36% | 413 | 72% | 183 | 72% |
| | 40 | 12.05 | 4.7 | 25% | 485 | 72% | 180 | 72% |
| | 41 | 12.35 | 4.4 | 53% | 307 | 75% | 184 | 75% |
| SPCB2 | 42 | 12.66 | 4.1 | 37% | 414 | 71% | 162 | 71% |
| | 43 | 12.96 | 3.8 | 49% | 331 | 64% | 189 | 64% |
| | 44 | 13.27 | 3.5 | 48% | 338 | 70% | 237 | 70% |
| | 45 | 13.57 | 3.2 | 49% | 332 | 73% | 196 | 73% |
| | 46 | 13.88 | 2.9 | 42% | 374 | 72% | 178 | 72% |
| | 47 | 14.18 | 2.6 | 56% | 290 | 74% | 184 | 74% |
| | 48 | 14.49 | 2.3 | 47% | 348 | 74% | 170 | 74% |
| | 49 | 14.79 | 2.0 | 58% | 276 | 73% | 169 | 73% |
| SPCB1 | 50 | 15.10 | 1.7 | 64% | 232 | 70% | 179 | 70% |
| | 51 | 15.40 | 1.4 | 45% | 355 | 64% | 193 | 64% |
| | 52 | 15.71 | 1.1 | 51% | 324 | 67% | 235 | 67% |
| | 53 | 16.01 | 0.8 | 61% | 256 | 72% | 218 | 72% |
| SPCM | 54 | 16.32 | 0.5 | 63% | 239 | 73% | 184 | 73% |
| | 55 | 16.62 | 0.2 | 55% | 293 | 73% | 178 | 73% |

In addition to the load allocations for effective shade in the study area, the following management activities are recommended for compliance with the water quality standards throughout the watershed:

- For U.S. Forest Service land, the riparian reserves in the Northwest Forest Plan are recommended for establishment of mature riparian vegetation.
- For privately owned forest land, the riparian vegetation prescriptions in the Forests and Fish Report are recommended for all perennial streams. Load allocations are included in this TMDL for forest lands in the South Prairie Creek watershed in accordance with the section of Forests and Fish entitled "TMDLs produced prior to 2009 in mixed use watersheds," using the shade curve methodology developed in the Upper White River Watershed Temperature TMDL (in press). Figure 19 presents the effective shade provided to streams of different NSDZ widths, varying stream aspects, and varying tree heights to represent an aging riparian forest. For example, for an east-west stream segment (aspect 90°) with a width of 66 ft (20 m) effective shade can be expected to increase from 18% to 35% to 62% to 80% as riparian tree height increases from 30 ft (9 m) to 60 ft (18 m) to 120 ft (37 m) to 180 ft (55 m).
- Instream flows and water withdrawals are managed through regulatory avenues separate from TMDLs. However, stream temperature is directly related to the amount of instream flow, and reductions in flow result in increases in temperatures. Given the temperature exceedance in South Prairie Creek and the inability to meet the temperature standard under full mature riparian vegetation, no further water withdrawals should be permitted. Voluntary retirement of existing water rights should be encouraged.
- While the study did not find evidence of channel widening in the South Prairie Creek watershed, future development and management activities should control potential channel widening processes.
- Hyporheic exchange flows and groundwater discharges are important to maintain the current temperature regime and reduce maximum daily instream temperatures. Factors that influence hyporheic exchange flow include the vertical hydraulic gradient between surface and subsurface waters as well as the conductivity of the bed sediments. Therefore, activities that reduce groundwater elevations could hamper the exchange of water through the hyporheic zone, which would result in raised stream temperatures. Similarly, activities that reduce the conductivity of bed sediments could increase stream temperatures. Therefore, future development and management activities should reduce upland and channel erosion and avoid sedimentation of fine materials in the stream substrate.

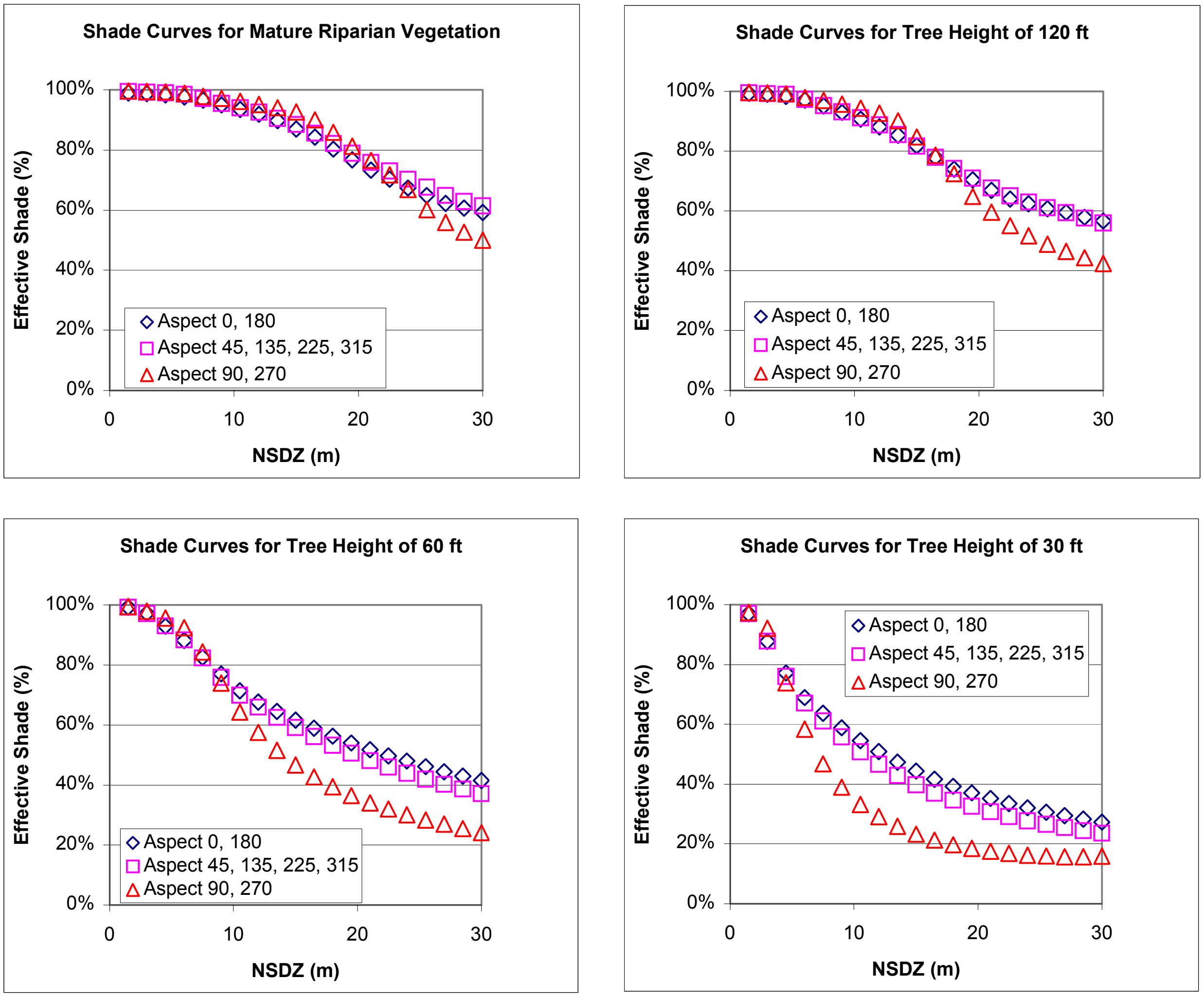



Figure 19. Effective shade provided by riparian vegetation of varying heights, stream aspect, and NSDZ width.

# Wasteload Allocations

## South Prairie Wastewater Treatment Plant

The South Prairie wastewater treatment plant discharges to South Prairie Creek under NPDES permit number 0040479. The permit does not have an effluent limit for temperature. Because South Prairie Creek currently exceeds the 18°C standard near the discharge, based on the monitored conditions of 2000 and 2001 and predicted 7Q2 and 7Q10 conditions, the water quality standards stipulate that "…no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C," which includes point source and nonpoint source contributions.

No mixing zone analysis was conducted for the South Prairie wastewater treatment plant. In the absence of a previously defined mixing zone, the effluent can mix with one-quarter of the stream discharge at the point of comparison with the water quality standards (Bailey, 2002).

Table 15 summarizes the information for the South Prairie wastewater treatment plant. When the plant discharges at the maximum summer flow reported in DMRs during the period January 1995 through December 2001, the resultant temperature increase in South Prairie Creek is 0.03°C, less than the 0.3°C maximum increase in the water quality standards. Even if the South Prairie WWTP discharged at the maximum daily rate reported in the DMRs[10] at the maximum temperature, the resultant temperature increase is 0.07°C, still less than the incremental increase allowed in the water quality standards. Therefore, the load allocation is set as a flow rate times the temperature, which cannot exceed

$$Q_{wwtp}\,(\text{mgd}) \bullet T_{wwtp}\,(°\text{C}) < (4.5\text{ mgd} + Q_{wwtp}) \bullet 0.1°\text{C}$$ [(11)]

where $Q_{wwtp}$ is the effluent flow rate in varying units and $T_{wwtp}$ is the effluent temperature. Figure 20 illustrates the effect. The wasteload allocation does not permit the facility to exceed an effluent temperature of 33°C at any time.

Table 15. South Prairie wastewater treatment plant and receiving water characteristics.

| ***Item*** | ***mgd*** | ***cfs*** | ***cms*** | ***°C*** |
|---|---|---|---|---|
| *South Prairie Creek critical conditions at WWTP discharge* | | | | |
| 7Q10 discharge | 18.10 | 28.0 | 0.79 | |
| *Allowable mixing volume* | | | | |
| 25% 7Q10 discharge | 4.52 | 7.00 | 0.198 | |
| *Theoretical temperature increase (maximum summer discharge and maximum summer temperature)* | | | | |
| Summer peak effluent discharge | 0.0354 | 0.055 | 0.0016 | |
| Summer peak effluent temperature | | | | 21.8 |
| Temperature at edge of mixing zone | | | | 18.03 |
| *Theoretical temperature increase (permit limit and maximum summer temperature)* | | | | |
| Permit limit for discharge | 0.0382 | 0.059 | 0.0017 | |
| Summer peak effluent temperature | | | | 21.8 |
| Temperature at edge of mixing zone | | | | 18.03 |
| *Theoretical temperature increase (maximum annual discharge and maximum summer temperature)* | | | | |
| Peak discharge in DMRs | 0.083 | 0.13 | 0.0036 | |
| Summer peak effluent temperature | | | | 21.8 |
| Temperature at edge of mixing zone | | | | 18.07 |

[10] Flows exceeded the permit limit of 0.0382 mgd (0.59 cfs or 0.0017 cms) in the DMRs. This analysis is presented for information purposes only and does not constitute an increase in the permit limit for flow.

[11] Equivalent to the following, in cms and cfs:

$Q_{wwtp}$ (cms) • $T_{wwtp}$ (°C) < (0.20 cms + $Q_{wwtp}$) • 0.1°C

$Q_{wwtp}$ (cfs) • $T_{wwtp}$ (°C) < (7 cfs + $Q_{wwtp}$) • 0.1°C

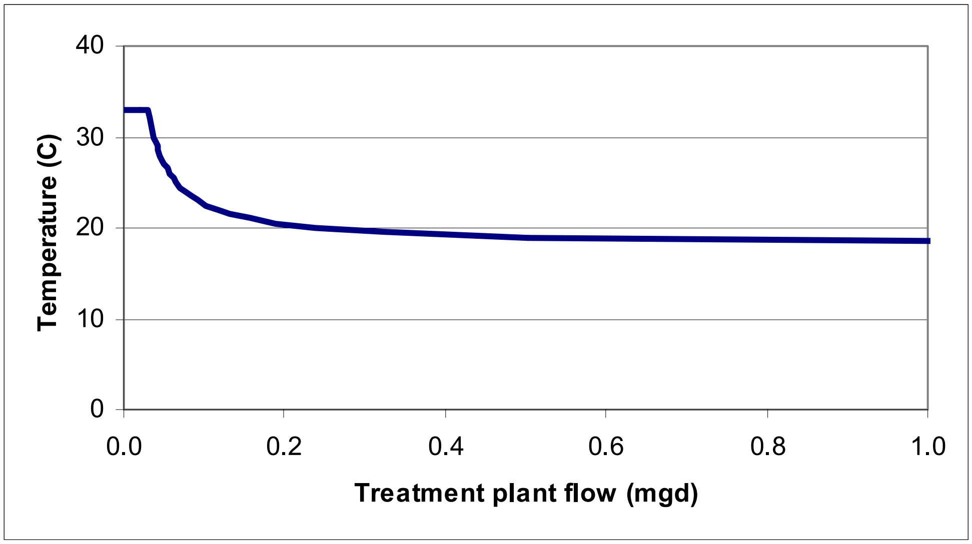



Figure 20. South Prairie wastewater treatment plant wasteload allocation.

## Wilkeson Wastewater Treatment Plant

The Wilkeson wastewater treatment plant discharges to Wilkeson Creek under NPDES permit number WA0023281. The permit does not have an effluent limit for temperature. Wilkeson Creek currently meets the 18°C standard near the discharge, based on the monitored conditions of 2000 and 2001, but exceeds the standard at the mouth. The water quality standards stipulate that "…no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C," which includes point source and nonpoint source contributions.

No mixing zone analysis was conducted for the Wilkeson wastewater treatment plant. In the absence of a previously defined mixing zone, the effluent can mix with one-quarter of the stream discharge at the point of comparison with the water quality standards (Bailey, 2002). No 7Q10 has been developed for Wilkeson Creek at the wastewater treatment plant. However, using the 2000 and 2001 flow monitoring data together with the long-term discharge record on South Prairie Creek, 7Q10 flow conditions are estimated to be 6.4 cfs (0.18 cms) based on the relationship between flows at the mouth of Wilkeson Creek to those recorded at the South Prairie USGS gage, then scaled to the tributary area upstream of the discharge point.

Table 16 summarizes the information for the Wilkeson wastewater treatment plant. When the plant discharges at the maximum summer flow reported in DMRs during the period February 1991 through December 2001, the resultant temperature increase in Wilkeson Creek is 0.05°C, less than the 0.3°C maximum increase in the water quality standards. Even if the plant discharged at the maximum daily rate reported in the DMRs at the maximum temperature, the resultant temperature increase is <0.3°C. Therefore, the load allocation is set as a flow rate times the temperature, which cannot exceed

$$Q_{wwtp}\ (\text{mgd}) \bullet T_{wwtp}\ (°\text{C}) < (4.2\ \text{mgd} + Q_{wwtp}) \bullet 0.1°\text{C}$$ [12]

where $Q_{wwtp}$ is the effluent flow rate in varying units and $T_{wwtp}$ is the effluent temperature. Figure 21 illustrates the effect. The wasteload allocation does not permit the facility to exceed an effluent temperature of 33°C at any time.

Table 16. Wilkeson wastewater treatment plant and receiving water characteristics.

| ***Item*** | ***mgd*** | ***cfs*** | ***cms*** | ***°C*** |
|---|---|---|---|---|
| *Wilkeson Creek critical conditions at WWTP discharge* | | | | |
| 7Q10 discharge | 4.2 | 6.4 | 0.18 | |
| *Allowable mixing volume* | | | | |
| 25% 7Q10 discharge | 1.04 | 1.61 | 0.046 | |
| *Theoretical temperature increase (maximum summer discharge and maximum summer temperature)* | | | | |
| Summer peak effluent discharge | 0.028 | 0.043 | 0.0012 | |
| Summer peak effluent temperature | | | | 20 |
| Temperature at edge of mixing zone | | | | 18.05 |
| *Theoretical temperature increase (maximum annual discharge and maximum summer temperature)* | | | | |
| Peak discharge in DMRs | 0.118 | 0.18 | 0.0052 | |
| Summer peak effluent temperature | | | | 20 |
| Temperature at edge of mixing zone | | | | 18.21 |

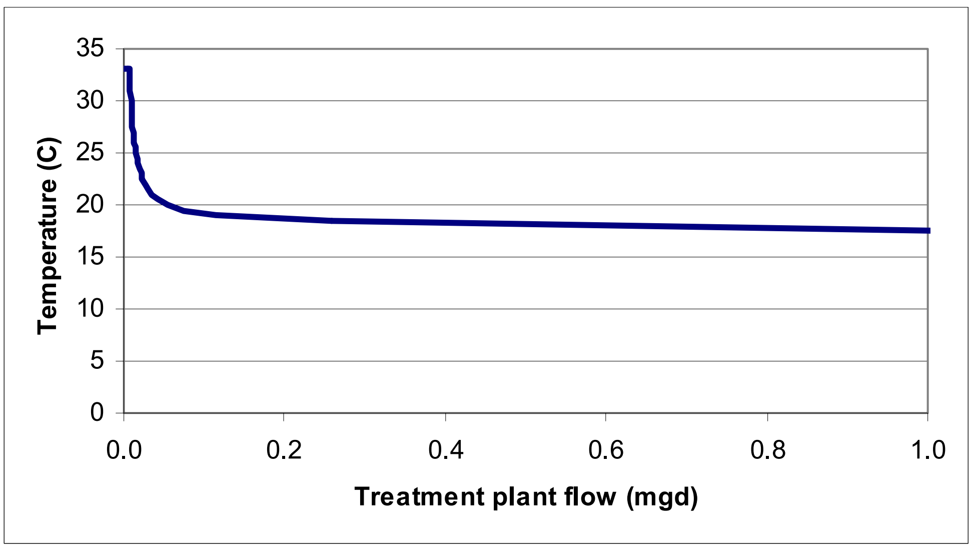



Figure 21. Wilkeson wastewater treatment plant wasteload allocation.

[12] Equivalent to the following, in cfs and cms:
$Q_{wwtp}\ (\text{cfs}) \bullet T_{wwtp}\ (°\text{C}) < (6.4\ \text{cfs} + Q_{wwtp}) \bullet 0.1°\text{C}$, or
$Q_{wwtp}\ (\text{cms}) \bullet T_{wwtp}\ (°\text{C}) < (0.18\ \text{cms} + Q_{wwtp}) \bullet 0.1°\text{C}$

## Summary of Load and Wasteload Allocations

Figure 22 compares current water temperature with the nonpoint source wasteload allocations and the point source load allocations for South Prairie Creek under 7Q10 conditions. Current conditions exceed water quality standards, which is the loading capacity. The effective shade allocations will decrease stream heating. The point sources contribute small thermal loads relative to the nonpoint influences on stream heating.

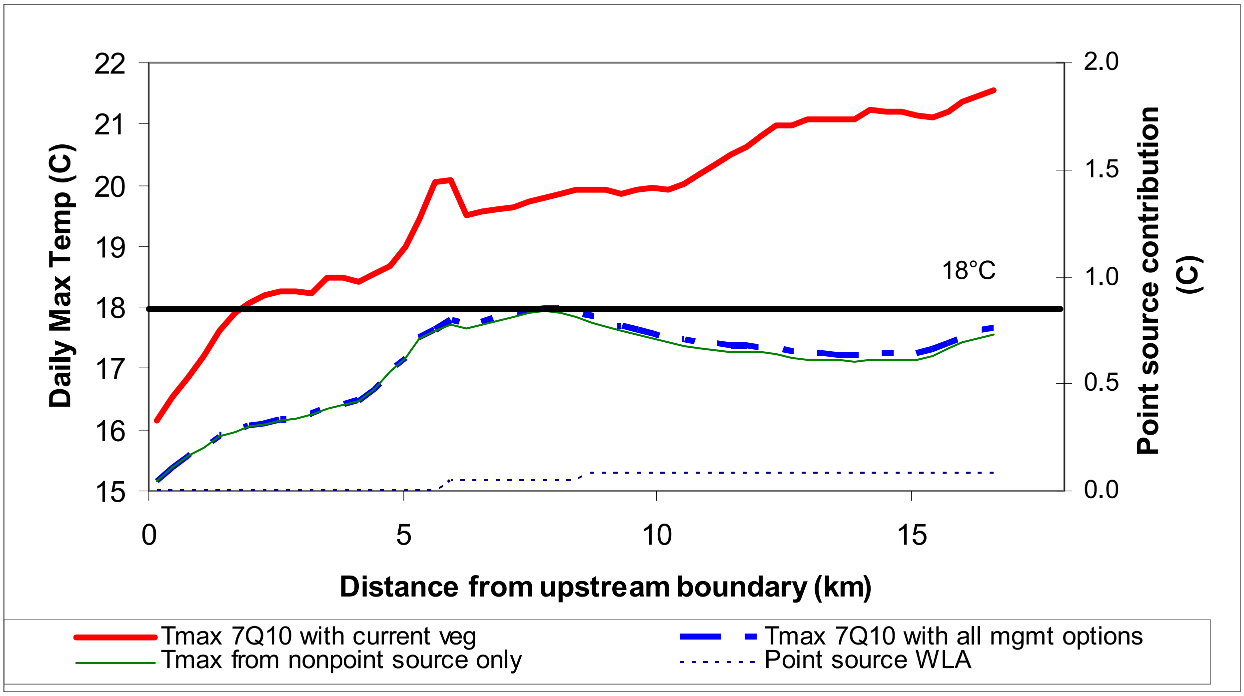



Figure 22. Current and allocated temperature along South Prairie Creek, distinguishing nonpoint source (thin green solid line) and point source (thin blue dashed line on secondary axis) contributions.

## Margin of Safety

The margin of safety accounts for uncertainty about pollutant loading and water-body response. In this TMDL, the margin of safety is addressed by using critical climatic conditions in the modeling analysis. Conservative assumptions for critical conditions include the following:

- The 90th percentile of air temperatures recorded at SeaTac Airport were used to develop reasonable worst case conditions air temperatures at South Prairie Creek.
- 7Q10 low-flow conditions were used to evaluate reasonable worst-case conditions. Typical conditions were evaluated using 7Q2 low flow conditions.

Model uncertainty was assessed by estimating the root-mean-square error (RMSE) of model predictions compared with observed temperatures during model validation. The warm validation data set resulted in a RMSE of 0.64°C, while the cool validation data set resulted in a RMSE of 0.91°C.

The load allocations are set to the effective shade provided by full mature riparian shade, which are the maximum values achievable in the South Prairie Creek system.

## Recommendations for Monitoring

To determine the effects of management strategies within the model area and upstream in both South Prairie Creek and Wilkeson Creek, regular monitoring is recommended. The model predicts local temperature maxima at two locations: the mouth of South Prairie Creek and at the confluence with Wilkeson Creek (Figure 16. At a minimum, continuous temperature monitors should be installed at the following sites: SPCSR, SPCWC, SPCSP, SPCB2, SPCM, WCM, and SKT165. Probes should be deployed from June through September to capture the critical conditions. Shade management practices involve the development of mature riparian vegetation, which requires more than five years to become established. Interim monitoring is recommended, however, perhaps at five-year intervals.

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# Appendices

# Appendix A

# Water Quality Data for South Prairie Creek and Tributaries

## Table A1. Phase I Assessment Water Quality Data

| | Date | Station | Fecal Coliform (#/100 ml) | *E. coli* (#/100 ml) | Entero-cocci (#/100 ml) | TPN (mg/L) | Ammonia (mg/L) | Nitrite/ Nitrate (mg/L) | Nitrite (mg/L) | Total Phosphorus (mg/L) | Ortho-phosphate (mg/L) | TSS (mg/L) | Calculated Organic Nitrogen (mg/L) | Flow (cfs) | pH | Temp (C) | DO (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Main Stem Stations | 7/19/00 | SPCSR | 8 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | 13.65 | NR |
| | 8/1/00 | SPCSR | 20 | 20 | 4 | 0.255 | .010U | 0.201 | .010U | 0.015 | .005U | 1U | 0.044 | NR | 7.56 | 14.6 | 9.9 |
| | 8/21/00 | SPCSR | 1 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | 7.89 | 10.95 | NR |
| | 9/5/00 | SPCSR | 2 | 2 | 44 | 0.208 | 0.010 U | 0.179 | 0.010 U | 0.017 | 0.005 U | 2 | NR | NR | 8.31 | 9.9 | 10.8 |
| | 9/19/00 | SPCSR | 22 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | 8.05 | 12.4 | NR |
| | 10/24/00 | SPCSR | 1 | 1 | NA | 0.288 | 0.010 U | 0.277 | 0.010 UJ | 0.012 | 0.005 U | 1 U | NR | NR | NR | 6.2 | 11.7 |
| | 12/18/00 | SPCSR | | | | | | | | | | | | NR | | 2.9 | NR |
| | 7/5/00 | SPCLB | | | | | | | | | | | | 90.86 | | | |
| | 7/19/00 | SPCLB | 11 | | | | | | | | | | | 54.82 | | 14.65 | |
| | 8/1/00 | SPCLB | 21 | 20 | 10 | 0.273 | .010U | 0.207 | .010U | 0.013 | 0.005 U | | 0.056 | 40.58 | 7.8 | 15.35 | 10 |
| | 8/21/00 | SPCLB | 6 | | | | | | | | | | | 39.12 | 7.67 | 12.4 | |
| | 9/5/00 | SPCLB | 4 | 4 | 32 | 0.225 | 0.010 U | 0.19 | 0.010 U | 0.018 | 0.005 | | | 37.22 | 7.5 | 11 | 10.8 |
| | 9/19/00 | SPCLB | 26 | | | | | | | | | | | 45.77 | 7.64 | 12.85 | |
| | 10/24/00 | SPCLB | 1 | 1 | NA | 0.271 | 0.010 U | 0.281 | 0.010 UJ | 0.013 | 0.005 U | | | 81.43 | | 6.4 | 11.65 |
| | 11/28/00 | SPCLB | | | | | | | | | | | | 126.00 | | | |
| | 12/18/00 | SPCLB | | | | | | | | | | | | 103.86 | | 3.1 | |
| | 7/12/00 | SPCSP | | | | | | | | | | | | SG27.55 | | 13.85 | |
| | 7/19/00 | SPCSP | 20 | | | | | | | | | | | SG27.51 | | 14.55 | |
| | 8/1/00 | SPCSP | 49 | 45 | 24 | 0.305 | .010U | 0.239 | .010U | 0.02 | 0.006 | | 0.056 | 51.58 | 8.1 | 16.85 | 10.25 |
| | 8/21/00 | SPCSP | 22 | | | | | | | | | | | NR | 7.68 | 13.75 | |
| | 9/5/00 | SPCSP | 29 | 23 | 89 | 0.248 | 0.010 U | 0.204 | 0.010 U | 0.02 | 0.007 | | | NR | 7.95 | 12.4 | 10.9 |
| | 9/19/00 | SPCSP | 50 | | | | | | | | | | | NR | 7.64 | 14.05 | |
| | 10/24/00 | SPCSP | 8 | 8 | NA | 0.336 | 0.010 U | 0.357 | 0.010 UJ | 0.015 | 0.006 | | | NR | | 7.4 | 11.5 |
| | 11/28/00 | SPCSP | | | | | | | | | | | | 201.82 | | | |
| | 12/18/00 | SPCSP | | | | | | | | | | | | NR | | 3.4 | |
| | 7/12/00 | SPCB4 | | | | | | | | | | | | NR | | 13 | |
| | 7/19/00 | SPCB4 | 120 | | | | | | | | | | | NR | | 13.85 | |
| | 8/1/00 | SPCB4 | 140 | 130 | 19 | 0.523 | 0.013 | 0.426 | .010U | 0.028 | 0.012 | | 0.084 | NR | 8.26 | 19 | 9.4 |
| | 8/21/00 | SPCB4 | 120 | | | | | | | | | | | 54.51 | 7.86 | 15.8 | |
| | 9/5/00 | SPCB4 | 760J | 740 | 73 | 0.504 | 0.010 U | 0.461 | 0.010 U | 0.029 | 0.013 | | | 48.82 | 7.77 | 12.7 | 10.7 |
| | 9/19/00 | SPCB4 | 300 | | | | | | | | | | | 66.78 | 7.62 | 14.7 | |
| | 10/24/00 | SPCB4 | 29 | 17 | NA | 0.468 | 0.010 U | 0.440 | 0.010 UJ | 0.018 | 0.008 | | | 103.33 | | 8.1 | 11.45 |
| | 12/18/00 | SPCB4 | | | | | | | | | | | | NR | | 3.95 | |
| | 7/5/00 | SPCM | | | | | | | | | | | | 165.82 | | | |
| | 7/12/00 | SPCM | | | | | | | | | | | | NR | | 12.8 | |
| | 7/19/00 | SPCM | 65 | | | | | | | | | | | 76.97 | | 13.6 | |
| | 8/1/00 | SPCM | 110 | 92 | 20 | 0.493 | .010U | 0.398 | .010U | 0.026 | 0.009 | 2 | 0.085 | 63.89 | 7.87 | 19.3 | 9.7 |
| | 8/21/00 | SPCM | 77 | | | | | | | | | | | 54.73 | 7.55 | 16.05 | |
| | 9/5/00 | SPCM | 160J | 140 | 86 | 0.498 | 0.010 U | 0.432 | 0.010 U | 0.028 | 0.01 | 2 | | 52.01 | 7.65 | 13 | 10.5 |
| | 9/19/00 | SPCM | 240 | | | | | | | | | | | 66.67 | 7.37 | 15.2 | |
| | 10/24/00 | SPCM | 23 | 14 | NA | 0.412 | 0.010 U | 0.441 | 0.010 UJ | 0.018 | 0.007 | 1 U | | 112.69 | | 8.4 | 11.15 |
| | 11/28/00 | SPCM | | | | | | | | | | | | 207.92 | | | |
| | 12/18/00 | SPCM | | | | | | | | | | | | 169.61 | | | |
| Tributary Stations | 7/5/00 | SD165 | | | | | | | | | | | | 1.80 | | | |
| | 7/12/00 | SD165 | | | | | | | | | | | | NR | | 14.8 | |
| | 7/19/00 | SD165 | 800 | | | | | | | | | | | 1.15 | | 15.05 | |
| | 8/1/00 | SD165 | 760 | 760 | 130 | 0.287 | 0.01 | 0.143 | .010U | 0.029 | 0.01 | | 0.134 | 1.19 | 7.32 | 16.1 | 9.3 |
| | 8/21/00 | SD165 | 670 | | | | | | | | | | | 1.36 | 7.35 | 11.6 | |
| | 9/5/00 | SD165 | 240 | 210 | 260 | 0.153 | 0.010 U | 0.089 | 0.010 U | 0.022 | 0.007 | | | 1.33 | 7.9 | 10.1 | 10.7 |
| | 9/19/00 | SD165 | 880 | | | | | | | | | | | 1.35 | 7.37 | 13.55 | |
| | 10/24/00 | SD165 | 40 | 37 | NA | 0.222 | 0.010 U | 0.156 | 0.010 UJ | 0.021 | 0.007 | | | 1.47 | | 6.4 | 11.05 |
| | 11/28/00 | SD165 | | | | | | | | | | | | 2.39 | | | |
| | 12/18/00 | SD165 | | | | | | | | | | | | 2.76 | | 2.8 | |
| | 7/12/00 | WCM | | | | | | | | | | | | | | 15.75 | |
| | 7/19/00 | WCM | 29 | | | | | | | | | | | 14.62 | | 16.45 | |
| | 8/1/00 | WCM | 41 | 39 | 37 | 0.441 | 0.011 | 0.356 | .010U | 0.029 | 0.011 | 1 | 0.074 | 11.72 | 8.02 | 17.8 | 9.5 |
| | 8/21/00 | WCM | 37 | | | | | | | | | | | 10.32 | 7.99 | 13.75 | |
| | 9/5/00 | WCM | 76 | 73 | 88 | 0.391 | 0.010 U | 0.328 | 0.010 U | 0.028 | 0.011 | 1 | | 10.40 | 7.82 | 11.9 | 10.85 |
| | 9/19/00 | WCM | 170 | | | | | | | | | | | 14.85 | 7.6 | 13.9 | |
| | 10/24/00 | WCM | 29 | 26 | NA | 0.616 | 0.010 U | 0.572 | 0.010 UJ | 0.019 | 0.008 | 1 | | 31.38 | | 6.6 | 11.4 |
| | 11/28/00 | WCM | | | | | | | | | | | | 76.33 | | | |
| | 12/18/00 | WCM | | | | | | | | | | | | 66.31 | | 3.4 | |
| Miscellaneous Locations | 8/21/00 | SD1 | 39 | | | | | | | | | | | | | | |
| | 8/21/00 | SD2 | 680J | | | | | | | | | | | | | | |
| | 9/5/00 | SDSR | 59 | | | | | | | | | | | | | | |
| | 9/19/00 | SPC246 | 57 | | | | | | | | | | | | | | |
| | 11/1/00 | SPCUS | 7 | | | | | | | | | | | | | | |
| | 9/19/00 | 14309 | 1400 | | | | | | | | | | | | | | |
| | 10/24/00 | EMERY1 | 8 | | | | | | | | | | | | | | |

U Not detected at or above the reported detection limit.
J Estimated values; very high density of organisms on plate, and actual concentration may be greater than or equal to reported results.
NR = not recorded.
NA = not applicable

## Table A2. Phase II Assessment Water Quality Data

| | Date | Station | Temperature (ºC) | Measured Streamflows (cfs) | Entero-cocci (#/100 ml) | Qualifier | Fecal Coliform (#/100 ml) | Qualifier |
|---|---|---|---|---|---|---|---|---|
| Main Stem Stations | 1/29/01 | SPCSR | 3.6 | NR | 1 | UJ | 2 | J |
| | 2/27/01 | SPCSR | 2.2 | NR | 1 | UJ | 1 | UJ |
| | 3/26/01 | SPCSR | 5.4 | NR | 1 | J | 1 | UJ |
| | 4/16/01 | SPCSR | 6.2 | NR | 1 | UJ | 5 | J |
| | 5/22/01 | SPCSR | 8.6 | NR | 1 | J | 7 | J |
| | 6/18/01 | SPCSR | 8.6 | NR | 1 | UJ | 6 | J |
| | 7/9/01 | SPCSR | 12 | NR | 2 | J | 12 | J |
| | 8/20/01 | SPCSR | 11.8 | NR | 5 | J | 9 | J |
| | 9/17/01 | SPCSR | 11.6 | NR | 45 | J | 13 | J |
| | 10/15/01 | SPCSR | 7.4 | NR | 41 | J | 7 | J |
| | 11/29/01 | SPCSR | 5.7 | NR | 2 | J | 10 | J |
| | 12/18/01 | SPCSR | 4.3 | NR | 4 | J | 3 | J |
| | 1/29/01 | SPCLB | 3.6 | 68.1 | 2 | J | 1 | UJ |
| | 2/27/01 | SPCLB | 2.3 | 50 | 3 | J | 2 | J |
| | 3/26/01 | SPCLB | 6.2 | 163 | 1 | | 3 | |
| | 4/16/01 | SPCLB | 6.8 | 125 | 1 | UJ | 2 | J |
| | 5/22/01 | SPCLB | 9.1 | 153 | 5 | J | 9 | J |
| | 6/18/01 | SPCLB | 9.4 | 158 | 100 | | 110 | |
| | 7/9/01 | SPCLB | 12.6 | 52.5 | 6 | J | 28 | J |
| | 8/20/01 | SPCLB | 12.2 | 30.07 | 4 | J | 16 | J |
| | 9/17/01 | SPCLB | 12.1 | 22.3 | 150 | J | 8 | J |
| | 10/15/01 | SPCLB | 7.8 | 88.8 | 35 | J | 19 | J |
| | 11/29/01 | SPCLB | 5.8 | 245 | 19 | | 22 | |
| | 12/18/01 | SPCLB | 4.5 | 430 | 3 | J | 4 | J |
| | 1/29/01 | SPCSP | 4.1 | 110.8 | 10 | | 21 | |
| | 2/27/01 | SPCSP | 3.9 | 79 | 6 | | 2 | |
| | 3/26/01 | SPCSP | 7.3 | NR | 60 | | 39 | |
| | 4/16/01 | SPCSP | 7.9 | 226.6 | 5 | | 14 | |
| | 5/22/01 | SPCSP | 11.2 | 209 | 8 | | 12 | |
| | 6/18/01 | SPCSP | 12.1 | 215 | 11 | | 21 | |
| | 7/9/01 | SPCSP | 14.5 | 70.3 | 16 | | 28 | |
| | 8/20/01 | SPCSP | 14.4 | 39.1 | 16 | | 41 | |
| | 9/17/01 | SPCSP | 12.8 | 29 | 41 | | 29 | |
| | 10/15/01 | SPCSP | 8.6 | 110.5 | 60 | | 24 | |
| | 11/29/01 | SPCSP | 5.8 | 596.6 | 270 | | 83 | |
| | 12/18/01 | SPCSP | 4.8 | 758.7 | 11 | | 10 | |
| | 1/29/01 | SPCOF | 4.2 | NR | 80 | | 15 | |
| | 2/27/01 | SPCOF | 3.4 | NR | 80 | J | 2 | J |
| | 3/26/01 | SPCOF | 7.7 | NR | 89 | | 58 | |
| | 4/16/01 | SPCOF | 7.9 | NR | 14 | | 19 | |
| | 5/22/01 | SPCOF | 11.2 | NR | 19 | | 17 | |
| | 6/18/01 | SPCOF | 12.2 | NR | 17 | | 12 | |
| | 7/9/01 | SPCOF | 14.3 | NR | 43 | | 50 | |
| | 8/20/01 | SPCOF | 13 | NR | 39 | | 160 | |
| | 9/17/01 | SPCOF | 12.8 | NR | 150 | | 200 | |
| | 10/15/01 | SPCOF | 8.6 | NR | 81 | | 74 | |
| | 11/29/01 | SPCOF | 5.8 | NR | 380 | | 110 | |
| | 12/18/01 | SPCOF | 4.8 | NR | 3 | | 4 | |
| | 7/9/01 | SPCID | 16.4 | NR | 24.5 | | 18 | |
| | 8/20/01 | SPCID | 13 | NR | 61 | | 200 | J |
| | 9/17/01 | SPCID | 12.8 | NR | 170 | | 92 | |
| | 10/15/01 | SPCID | 9.1 E | NR | 270 | | 110 | |
| | 11/29/01 | SPCID | NR | NR | 440 | | 120 | |
| | 12/18/01 | SPCID | 5 | NR | 20 | | 18 | |
| | 1/29/01 | SPCB4 | 4.3 | NR | 970 | | 690 | J |
| | 2/27/01 | SPCB4 | 5 | 82.3 | 40 | | 3 | U |
| | 3/26/01 | SPCB4 | 7.8 | NR | 70 | | 68 | |
| | 4/16/01 | SPCB4 | 8.9 | NR | 27 | | 10 | |
| | 5/22/01 | SPCB4 | 13.2 | 185 | 230 | | 120 | J |
| | 6/18/01 | SPCB4 | 13.1 | NR | 11 | | 51 | |
| | 7/9/01 | SPCB4 | 16.2 | NR | 21 | | 19 | |

| | Date | Station | Temperature (ºC) | Measured Streamflows (cfs) | Entero-cocci (#/100 ml) | Qualifier | Fecal Coliform (#/100 ml) | Qualifier |
|---|---|---|---|---|---|---|---|---|
| | 8/20/01 | SPCB4 | 15.1 | 49.5 | 51 | | 37 | |
| | 9/17/01 | SPCB4 | 12.8 | 37.9 | 100 | | 110 | |
| | 10/15/01 | SPCB4 | 9.6 | 110 | 150 | | 55 | |
| Main Stem Stations | 11/29/01 | SPCB4 | NR | NR | 850 | J | 110 | |
| | 12/18/01 | SPCB4 | 5 | NR | 110 | | 44 | |
| | 1/29/01 | SPCB2 | 4.4 | NR | 930 | J | 260 | J |
| | 2/27/01 | SPCB2 | 5.2 | NR | 23 | | 3 | |
| | 3/26/01 | SPCB2 | 7.8 | NR | 220 | J | 260 | J |
| | 4/16/01 | SPCB2 | 9.1 | NR | 34 | | 31 | |
| | 5/22/01 | SPCB2 | 14.1 | NR | 200 | | 150 | J |
| | 6/18/01 | SPCB2 | 13.3 | 215 | 29 | | 71 | |
| | 7/9/01 | SPCB2 | 16.6 | NR | 21 | | 19 | |
| | 8/20/01 | SPCB2 | 15.7 | 43.8 | 110 | | 48 | |
| | 9/17/01 | SPCB2 | 13.1 | 39.6 | 120 | | 71 | |
| | 10/15/01 | SPCB2 | 9.8 | 118 | 140 | | 57 | |
| | 11/29/01 | SPCB2 | NR | NR | 890 | J | 80 | |
| | 12/18/01 | SPCB2 | 5.1 | NR | 88 | | 40 | |
| | 1/29/01 | SPCB1 | 4.4 | 126 | 770 | J | 260 | J |
| | 2/27/01 | SPCB1 | 5.4 | NR | 14 | | 9 | |
| | 3/26/01 | SPCB1 | 7.9 | NR | 300 | | 310 | |
| | 4/16/01 | SPCB1 | 9.2 | 225 | 26 | | 9 | |
| | 5/22/01 | SPCB1 | 14.6 | 202 | 52 | | 120 | |
| | 6/18/01 | SPCB1 | 13.6 | 220 | 37 | | 29 | |
| | 7/9/01 | SPCB1 | 17.5 | 81.1 | 21 | | 71 | |
| | 8/20/01 | SPCB1 | 15.6 | 45.9 | 35 | | 41 | |
| | 9/17/01 | SPCB1 | 13 | 39.8 | 180 | J | 110 | |
| | 10/15/01 | SPCB1 | 9.8 | 118 | NR | | NR | |
| | 11/29/01 | SPCB1 | NR | 550 | 900 | J | 100 | |
| | 12/18/01 | SPCB1 | 5.1 | 700 | 71 | | 43 | |
| | 1/29/01 | SPCM | 4.6 | 112 | 770 | | 400 | J |
| | 2/27/01 | SPCM | 5.3 | 83 | 6 | | 3 | |
| | 3/26/01 | SPCM | 8.3 | 278 | 160 | | 250 | J |
| | 4/16/01 | SPCM | 9.3 | NR | 23 | | 14 | |
| | 5/22/01 | SPCM | 15 | 200 | 81 | | 120 | |
| | 6/18/01 | SPCM | 13.6 | 209 | 25 | | 80 | |
| | 7/9/01 | SPCM | 17.9 | 85.9 | 11 | | 72 | |
| | 8/20/01 | SPCM | 15.7 | 48.3 | 75 | | 41 | |
| | 9/17/01 | SPCM | 13.1 | 37.8 | 390 | | 160 | J |
| | 10/15/01 | SPCM | 10.2 | 106 | 120 | | 60 | |
| | 11/29/01 | SPCM | NR | NR | 1000 | J | 170 | |
| | 12/18/01 | SPCM | 5.1 | NR | 80 | | 31 | |
| Tributary Stations | 1/29/01 | SKT165 | NR | 2.08 | NR | | NR | |
| | 2/27/01 | SKT165 | NR | 1.76 | NR | | NR | |
| | 3/26/01 | SKT165 | 7 | 13.2 | 280 | | 680 | |
| | 4/16/01 | SKT165 | NR | NR | NR | | NR | |
| | 5/22/01 | SKT165 | 10.9 | 1.74 | NR | | NR | |
| | 6/18/01 | SKT165 | 10.3 | 3.74 | NR | | NR | |
| | 7/9/01 | SKT165 | 13.5 | 0.9 | NR | | NR | |
| | 8/20/01 | SKT165 | 11.6 | 0.84 | NR | | NR | |
| | 9/17/01 | SKT165 | 11.9 | 1.02 | NR | | NR | |
| | 10/15/01 | SKT165 | 8 | 3.21 | NR | | NR | |
| | 11/29/01 | SKT165 | NR | 21.1 | NR | | NR | |
| | 12/18/01 | SKT165 | 4 | 14 | NR | | NR | |
| | 1/29/01 | WCM | 3.9 | 35.6 | 5 | J | 11 | J |
| | 2/27/01 | WCM | 2.75 | 25.4 | 8 | J | 3 | J |
| | 3/26/01 | WCM | 7.1 | 78.7 | 29 | | 5 | |
| | 4/16/01 | WCM | 7.6 | NR | 15 | | 8 | |
| | 5/22/01 | WCM | 11.4 | 46.7 | 11 | | 19 | |
| | 6/18/01 | WCM | 11.8 | 55.6 | 23 | | 19 | |
| | 7/9/01 | WCM | 14.2 | 20.3 | 32 | J | 53 | J |
| | 8/20/01 | WCM | 12.4 | 11.6 | 57 | J | 130 | J |
| | 9/17/01 | WCM | 12.6 | 8.57 | 140 | | 46 | |

| | Date | Station | Temperature (ºC) | Measured Streamflows (cfs) | Entero-cocci (#/100 ml) | Qualifier | Fecal Coliform (#/100 ml) | Qualifier |
|---|---|---|---|---|---|---|---|---|
| Tributary Stations | 10/15/01 | WCM | 8.9 | 27.3 | 140 | | 200 | |
| | 11/29/01 | WCM | 5.9 | 168 | 74 | | 34 | |
| | 12/18/01 | WCM | 4.9 | 247.0 | 7 | | 8 | |
| | 1/29/01 | SPCWC | 3.9 | NR | | | | |
| | 2/27/01 | SPCWC | 3 | NR | | | | |
| | 3/26/01 | SPCWC | 6.8 | NR | | | | |
| | 4/16/01 | SPCWC | 7.3 | NR | | | | |
| | 5/22/01 | SPCWC | 10.2 | NR | | | | |
| | 6/18/01 | SPCWC | NR | 149 | | | | |
| | 7/9/01 | SPCWC | 13.5 | NR | | | | |
| | 8/20/01 | SPCWC | 12.7 | NR | | | | |
| | 9/17/01 | SPCWC | 12.5 | NR | | | | |
| | 10/15/01 | SPCWC | NR | 79.7 | | | | |
| | 11/29/01 | SPCWC | 5.8 | NR | | | | |
| | 12/18/01 | SPCWC | 4.5 | NR | | | | |
| | 1/29/01 | T1 | NR | NR | 8 | U | 15 | |
| | 2/27/01 | T1 | NR | NR | 650 | J | 68 | |
| | 3/26/01 | T1 | NR | NR | 840 | | 950 | J |
| | 4/16/01 | T1 | NR | NR | 210 | | 1100 | |
| | 5/22/01 | T1 | NR | NR | 210 | | 540 | |
| | 6/18/01 | T1 | 15.3 | NR | 69 | | 210 | |
| | 7/9/01 | T1 | 13.5 | NR | 130 | | 83 | |
| | 8/20/01 | T1 | 12.2 | NR | 84 | | 84 | |
| | 9/17/01 | T1 | 11.7 | NR | 240 | | 450 | |
| | 10/15/01 | T1 | 10.4 | NR | 140 | | 140 | |
| | 11/29/01 | T1 | NR | NR | 13000 | J | 1500 | |
| | 12/18/01 | T1 | 6.1 | NR | 220 | | 240 | |
| | 7/9/01 | T1ID | 15.9 | NR | 200 | | 340 | |
| | 8/20/01 | T1ID | 13 | NR | 2100 | J | 2200 | J |
| | 9/17/01 | T1ID | 12.2 | NR | 230 | | 280 | |
| | 10/15/01 | T1ID | 11.4 E | NR | 230 | | 550 | |
| | 11/29/01 | T1ID | NR | NR | 14000 | J | 1400 | |
| | 12/18/01 | T1ID | 6.2 | NR | 380 | | 290 | |
| | 1/29/01 | SKTM | 3.9 | NR | 63 | J | 28 | J |
| | 2/27/01 | SKTM | 2.5 | NR | 36 | J | 48 | J |
| | 3/26/01 | SKTM | NR | NR | NR | | NR | |
| | 4/16/01 | SKTM | 8.3 | NR | 49 | J | 92 | J |
| | 5/22/01 | SKTM | 11 | NR | 13 | | 320 | |
| | 6/18/01 | SKTM | 10.3 | NR | 6 | | 7 | |
| | 7/9/01 | SKTM | 12.7 | NR | 140 | J | 180 | J |
| | 8/20/01 | SKTM | 11.7 | NR | 300 | J | 230 | J |
| | 9/17/01 | SKTM | 11.9 | NR | 330 | | 94 | |
| | 10/15/01 | SKTM | 8.4 | NR | 130 | | 140 | |
| | 11/29/01 | SKTM | 5.8 | NR | 1900 | J | 500 | |
| | 12/18/01 | SKTM | 4.3 | NR | 54 | J | 26 | J |
| Point Source | 1/29/01 | OF | NR | NR | 8 | | 37 | |
| | 2/27/01 | OF | NR | NR | 3 | | 7 | |
| | 3/26/01 | OF | NR | NR | 57 | | 80 | |
| | 4/16/01 | OF | NR | NR | 4 | | 1 | |
| | 5/22/01 | OF | NR | NR | 7 | | 25 | |
| | 6/18/01 | OF | NR | NR | 22 | | 76 | |
| | 7/9/01 | OF | NR | NR | 10 | | 19 | |
| | 8/20/01 | OF | NR | NR | 1 | U | 1 | |
| | 9/17/01 | OF | NR | NR | 2 | | 1 | U |
| | 10/15/01 | OF | NR | NR | 1 | | 3 | |
| | 11/29/01 | OF | NR | NR | 39 | | 82 | |
| | 12/18/01 | OF | NR | NR | 2 | | 1 | U |

U Not detected at or above the reported detection limit.
J Estimated values; very high density of organisms on plate, and actual concentration may be greater than or equal to reported results.
NR = not recorded.

# Appendix B

# Example of Vegetation GIS Data Layer Developed for South Prairie Creek

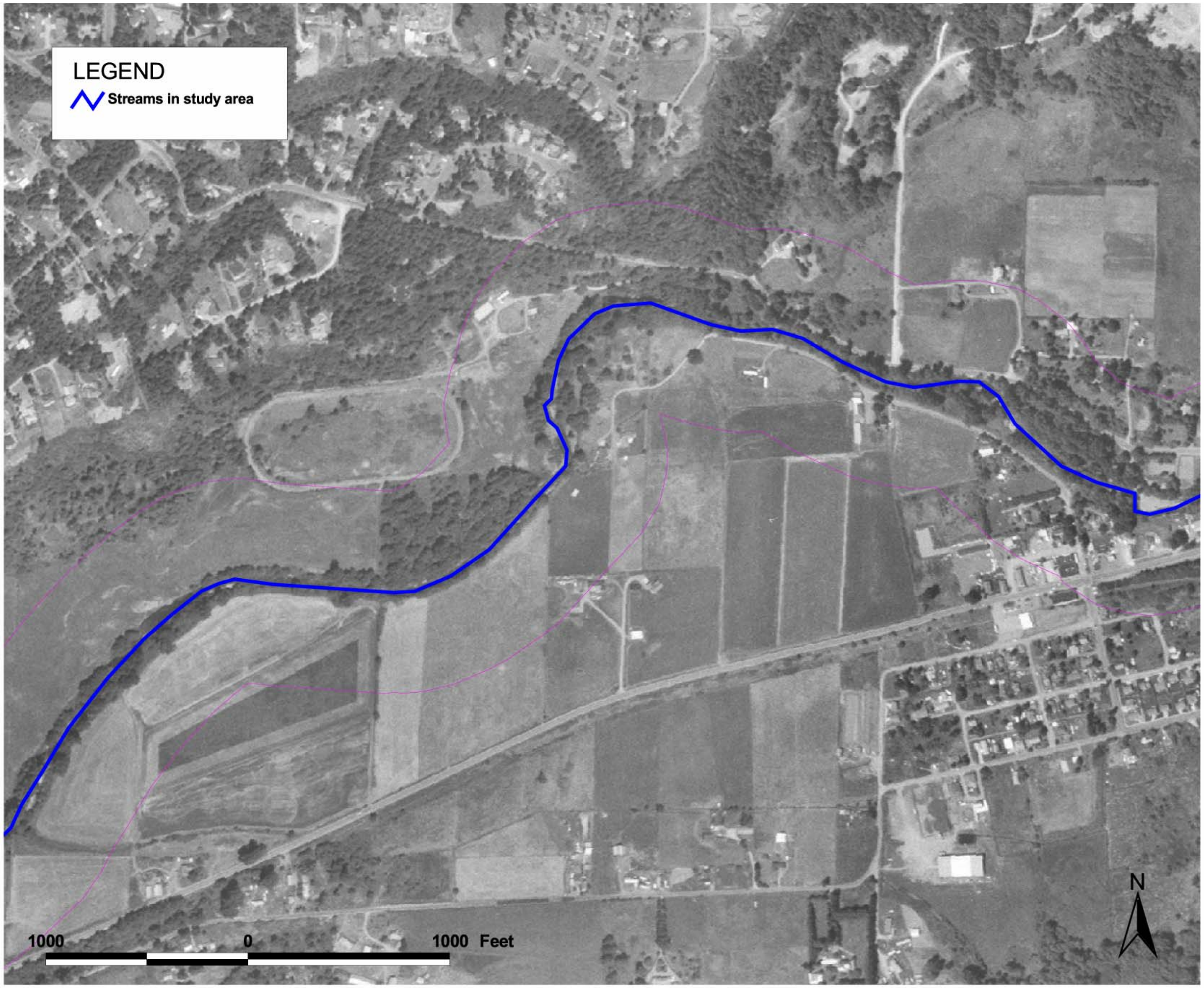


Figure B-1. Digital orthophoto of South Prairie Creek near the town of South Prairie.

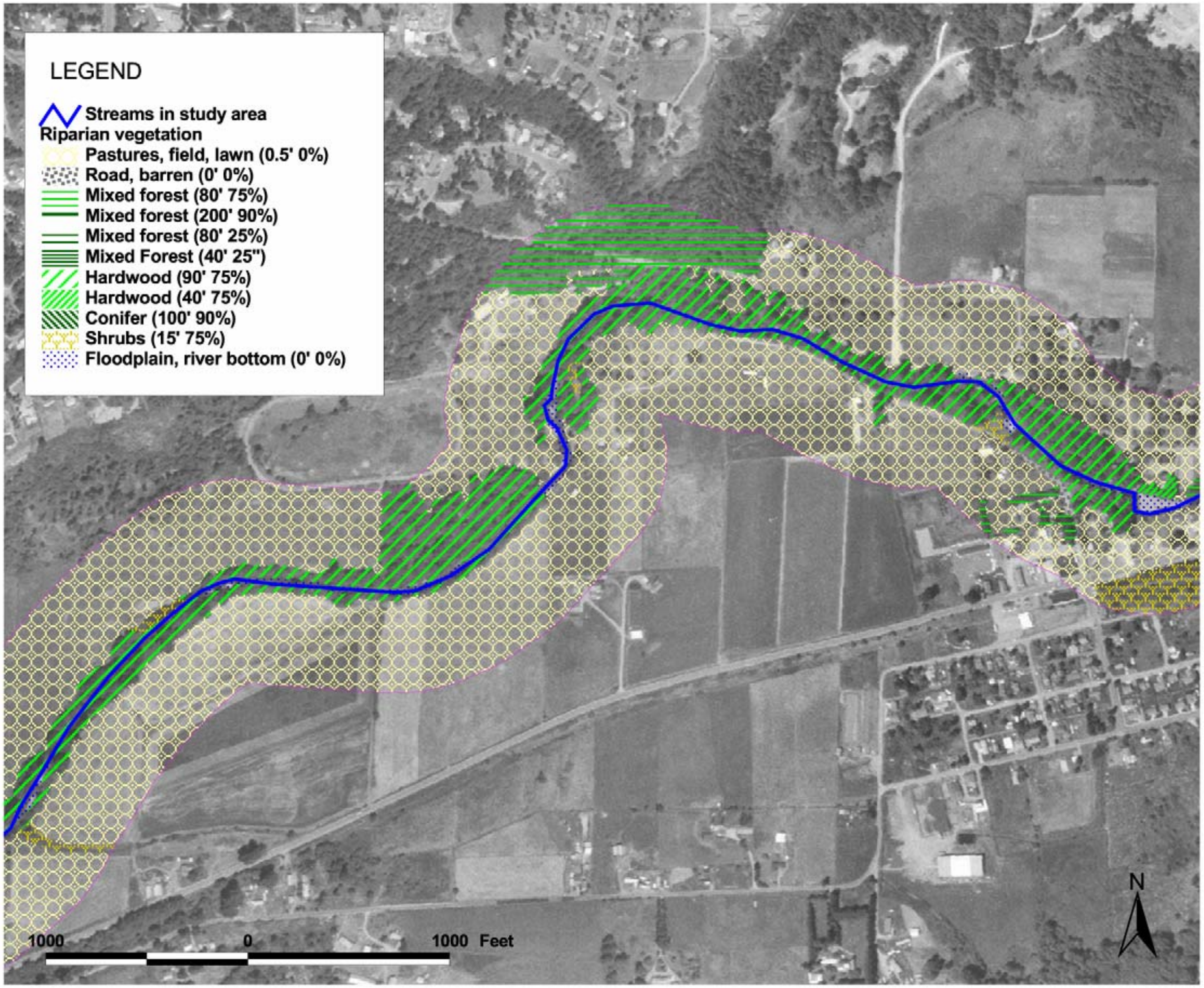


Figure B-2. Digital orthophoto, with overlay of vegetation polygons derived from orthophotos and habitat surveys.